

The Blast Furnace and Steel Plant

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The Blast Furnace *and* Steel Plant

Vol. XV

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No. 3

EXECUTIVES

A PERSON to whom this term is applied is, in the common acceptance of the term, one who possesses to a high degree those attributes which enable him to execute his own, or the plans of others. The term is one of degree, for there are executives hardly worthy of the appellation, while on the other hand, some are so richly endowed as to approach the Superman. Among the attributes which are requisite for this latter type of executive ability are Personality, Courage, Judgment, Initiative and Poise. With these attributes there is a blending of others which differentiates the type of Executive. Thus the so-called "leader of men" may be of the militaristic type, in which case he relies on his position to give weight to his commands. He rules by fear, but his executive powers may be of a low order. The true executive will have a certain sympathy for those whom he directs, hence his control will be more durable. Between the two extreme types may be found others of varying capabilities.

There is probably no industry which has had executives of a higher type than those to be found in our iron and steel companies. In the past generation, the names of Andrew Carnegie, C. S. Price, James Burden, W. L. Jones and others come to mind. These men not only were competent to carry to fruition their own ideas, but they had the ability to choose men as aides who were also executives, in the true sense of the word. As executive ability commands a higher price than any other, such men received a greater recompense than did those whose duties were confined to strictly technical service, and this is generally the case. There are men, though, who are so happily endowed as to possess mechanical skill and with this, ability as leaders, and for such there is ever a demand.

The history of a steel plant is usually written in terms of tons of output, quality of output or, more frequently, in relation to its financial rating. If written in terms of character of the men who founded the plant, and of those who carried on the work, its life would be presented in a most enlightening manner. For while it may be true that some plants have been a success with executives of no great prominence, the converse is undoubtedly true, that those companies that have been eminently successful have been dominated by executives of more than usual ability.

Some Blast Furnace Reactions Analyzed

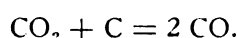
"Solution Loss" and Air Volume Calculated—By Equations the Basis for Gas Formation Is Rendered Apparent—Detailed Method of Determining Air Volumes Is Given

By GEORGE TOBIN*

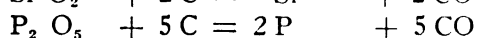
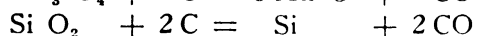
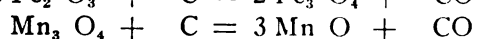
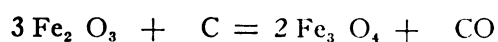
AS early as 1870 the phenomena of the reduction of carbon dioxide by carbon at temperature in a blast furnace was known to furnacemen. In explaining the dissociation of carbon monoxide, which had also been discovered, it was very definitely stated by Gruener and others that the carbon liberated in the reaction: $2\text{CO} \rightarrow \text{CO}_2 + \text{C}$, with the ore acting as catalytic agent, was deposited in the interstices of the ore in the lower temperature zones of the upper furnace. This deposited carbon was described as descending in the ore until it had been "dissolved" by the CO_2 and then passing upward again as CO , it was either redeposited or left the furnace in the gaseous state.

What Bell and Gruener called "dissolving of carbon by the dioxide," is, among modern blast furnacemen, known variously as "solution loss," "carbon transfer," etc. It represents that part of the carbon content of the coke and limestone charged in a furnace which is gasified before it reaches the tuyeres in the following reactions:

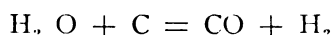
1—In the upper stack where, at temperatures above 1000 deg. F., carbon, in the presence of CO_2 , is gasified:



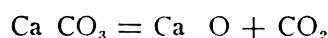
2—The direct reduction of the iron oxides by carbon at low temperatures and, at somewhat higher temperatures, of the oxides of silicon, manganese, and phosphorus, typical of which are:



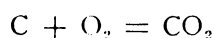
3—Some carbon reacts with the moisture of the blast, and a relatively small amount with the nitrogen of the blast:



4—The limestone yields its carbonate at temperatures above 1400 deg. F.:



Solution loss does not include that carbon gasified in the tuyere zone. In this plane, which extends some two feet above the tuyere level, the oxygen of the blast is entirely consumed in the combustion of the coke, viz.:



The ultimate product of the oxidation at the tuyeres is CO , the medium by which the principal function of the furnace is performed, namely the re-

duction of the iron oxides of the ore. The heat necessary to smelt the ore and meet the thermal requirements of the hearth demanded by the iron and slag, is produced by the intermediary stage in the tuyere oxidation, the highly exothermic evolution of CO_2 .

Since the carbon consumed in the above reactions supplies the essential elements of the blast furnace—heat and a reducing gas—that part of it which reduces the dioxide in the endothermic reaction is not considered a solution loss.

That part of the carbon charged in the furnace which is neither gasified in the stack nor at the tuyeres, leaves the furnace as flue dust or in the iron as combined and graphite carbon.

Items 1 to 4 above represent the solution loss in that the reactions involved deprive the tuyeres of carbon and since the reactions are all heat-absorbing, they use carbon in the most inefficient modes of reduction of the several oxides.

The efficiency of the blast furnace is dependent upon its ability to oxidize coke at the tuyeres. The greater the quantity of carbon that is burned to CO_2 , the greater the quantity of heat developed. The lower the solution loss, therefore, the higher the thermal economy of the furnace. The rate at which the coke is oxidized and consequently the speed with which the reducing element, CO , is evolved, determines the speed of the entire smelting operation. The faster a furnace "works," the greater the production of that furnace.

Although this carbon transfer has long been acknowledged and its importance recognized, very little work has been done in determining values for it. Where figures are obtainable they are at best, estimates. Perrott and Kinney, as a result of their investigations, conclude that approximately one-third of the coke charge is lost before reaching the tuyeres. Linhardt, in measuring air requirements, fixes the carbon delivered to the tuyeres as 80 per cent of that charged—accepting a 20 per cent loss as a working average. Both of these "losses" include flue loss and iron carburization.

Since this carbon loss varies and is peculiar to the individual furnace and inasmuch as it must be accounted for in determining air delivery, a method of calculating both has been developed which is offered for practical use by the furaceman.

The four methods generally used in determining the amount of air blown in a furnace are as follows:

Methods for Calculating Air Volume

1—Assuming ideal working, i.e., supposing all the carbon of the coke reaches the tuyeres intact and calculating the oxygen corresponding. But even in the case of a good working furnace, this carbon which reaches the tuyeres may be some 20 or 30 per cent less than the total carbon charged, which of course, involves an erroneous estimate of the air.

2—A method based on a formula for the flow of

*Engineer, Inland Steel Company.

a gas through a restricted orifice. Figures obtained from this method must be corrected for temperature, pressure, and moisture. Measuring instruments based on this principle are guaranteed only within 5 per cent by their manufacturers.

3—Where air measurement is based on the volume passed through a blowing cylinder, the losses due to leaks in valves, mains, ports, and hot blast stoves as well as that air which is thrown back in the cylinder itself, contradict accuracy.

4—To use oxygen as a base in determining the air blown involves a mass of calculation and is inaccurate insofar as it entails the use of figures for the ore charge. Ores charged in a furnace are usually mixed in the stock house and weighed but once. Stock house scale cars and the mixture percentages are precise to the degree of care exercised by the operator. Experience proves such weights as are thus obtained to be subject to numerous errors which disqualify their use in such a calculation.

In this calculation, carbon is used as the base in the deduction of the actual air delivery for several reasons. First, it permits the simultaneous development of both solution loss and air volume. Second, the calculation is less involved than it would be were oxygen used as the base, facilitating its use by the furnaceman. Third, the coke and limestone charged in a furnace are, as a rule, more accurately measured than are the ore charges. Limestone since there is so much less of it than either coke or ore, and coke, since it is usually weighed twice before charging, in the cars as delivered to the stock house bins, and again in the scale cars as delivered to the skips or gauged by volume in the skips. Gauging by volume, where some uniformity of coke size is obtained, is found to approximate very closely the car weights delivered to the furnace bins. This double weighing gives the furnaceman a good check on the weights of the larger of the carbonaceous charge. Carbon charged to the furnace in the ores as calcium and magnesium carbonates were, in this instance, found negligible although their presence in very small amounts is highly probable as the loss on ignition shown by the ore analyses indicates. Where ignition loss of ore is high it can usually be accounted for by the decomposition of ferric hydroxides on heating. Were carbonates present in an appreciable amount in the ores, such carbon would be included in the calculation along with that of the coke and limestone or other flux. Monthly figures were used in the calculation because they are more representative and minimize the inconsistencies of daily figures caused by the minor variables of furnace operation.

Basis for Determinations

Any attempt at determining the actual amount of air blown in a furnace must be based on the theoretical amount of air required to burn one pound of carbon to CO, 76 cu. ft. at 62 deg. F. This established, and the coke and limestone charge known, it remains to ascertain what part of the carbon charged actually reached the tuyere or oxidizing zone. Flue dust, iron carburization, and solution losses must therefore be accounted for.

The furnace data requisite to the calculation is given together with tables of gas analyses, component gas weights, etc. Although the presence of methane in blast furnace gas is denied by Kinney and others, it is included in the analysis used here because it is

invariably found in the gas as analyzed by the chemists in steel plant laboratories. To be of practical use, any method offered a furnaceman must include only that data which is at his command and in the form in which he is accustomed to receive it.

TABLE I—FURNACE DATA (November, 1925)

No. 2 Furnace, Inland Steel Company

Height of furnace.....	91 ft. 5 in.
Hearth diameter.....	17 ft. 3 in.
Number of tuyeres.....	12
Tons iron produced.....	20,746 tons
Total coke charged.....	16,357 tons
Per cent fixed carbon in coke.....	90 per cent
Total limestone charged.....	6,358 tons
Per cent carbon in stone.....	12 per cent
Per cent carbon in iron (total).....	4 per cent
*Total flue dust produced.....	2,700 tons
Per cent carbon in flue dust.....	5 per cent
Mean temperature atmosphere.....	40 deg. F.
Time furnace in blast (month).....	41,806 min.

*This figure includes the flue dust carried out in the gas washer discharge water. Samples of this water were taken at half hour intervals regularly and the dust content determined per U. S. gallon. The water entering the washer was measured by a Venturi meter.

TABLE II
GAS ANALYSIS AND COMPONENT WEIGHTS

Gas	Wt. in lbs. 1 cu. ft.	Per cent in B. F. gas	Wt. in lbs. in 1 cu. ft. B. F. gas
CO.....	.0734	24	.017616
CO ₂	.1156	12	.013872
N ₂	.0737	62	.045694
CH ₄	.0421	2	.000842

TABLE III—CARBON IN BLAST FURNACE GAS

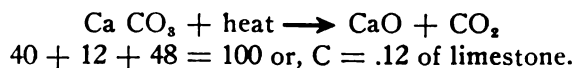
Gas	Lbs. C. in 1 cu. ft.
CO.....	.00754968
CO ₂	.00378324
N ₂.....	.....
CH ₄	.00063120

Calculation

The coke consumption for one month for one furnace was:

$$16,357 \text{ tons} \times 90 \text{ per cent F. C.} = 14,721 \text{ tons C.}$$

The carbon from the limestone charged was:



The total limestone charged was:

$$6,358 \text{ tons} \times 12 \text{ per cent C.} = 763 \text{ tons C.}$$

The total carbon charged in coke and limestone was:

$$14,721 \text{ tons} + 763 \text{ tons} = 15,484 \text{ tons C.}$$

The furnace produced:

$$20,746 \text{ tons iron} \times 4 \text{ per cent C.} = 830 \text{ tons C.}$$

$$2,700 \text{ tons flue dust} \times 5 \text{ per cent C.} = 135 \text{ tons C.}$$

The total C. unavailable for gas was: 965 tons C.

$$15,484 \text{ tons} - 965 \text{ tons} = 14,519 \text{ tons C. to gas.}$$

Expressing the gasified C. in pounds:

$$14,519 \text{ tons} \times 2000 \text{ lbs.} = 29,038,000 \text{ lbs. C. to gas 1 month.}$$

Table III of component gas weights gives:

1 cu. ft. blast furnace gas contains, .012 lbs. C.

There were produced, therefore:

$$29,038,000 \text{ lbs.} + .012 \text{ lbs.} = 2,419,833,333 \text{ cu. ft. gas.}$$

Since the N_2 entering with the blast leaves the furnace in the top gas, unchanged, using Table II, the weight of the N_2 in the top gas was:

$$2,419,833,333 \text{ cu. ft.} \times .046 \text{ lbs.} = 111,312,333 \text{ lbs. } N_2 \text{ in gas.}$$

The N_2 in the gas known, and consequently the N_2 in the air blown known, the total air blown at the tuyeres was:

$$111,312,333 \text{ lbs.} \times \frac{100}{77} = 144,561,400 \text{ lbs. air 1 month.}$$

The air volume at 40 deg. F. blown was: (1 cu. ft. air at 40 deg. F. = .0795 lbs.)

$$144,561,400 \text{ lbs.} \div .0795 \text{ lbs.} = 1,818,382,390 \text{ cu. ft. air 1 month.}$$

The air per pound of coke charged and per pound of carbon delivered to the tuyeres was therefore:

$$1,818,382,390 \text{ cu. ft.} \div 32,714,000 \text{ lbs.} = 55.6 \text{ cu. ft. per lb. coke.}$$

$$1,818,382,390 \text{ cu. ft.} \div 29,038,000 \text{ lbs.} = 62.6 \text{ cu. ft. per lb. C.}$$

At 62 deg. F. 76 cu. ft. of free air are required to burn one pound of carbon to CO. The mean temperature of the atmosphere for the month was 40 deg. F. Correcting the air requirement figure for temperature:

$$76 \text{ cu. ft.} \times \frac{459.4^\circ + 40^\circ}{459.4^\circ + 62^\circ} = 72.8 \text{ cu. ft. at } 40^\circ \text{ F.}$$

The calculation has given 62.6 cu. ft. of air at 40 deg. F. per pound of carbon burned, the difference between which and the 72.8 cu. ft. actually required is explained by the carbon loss not deducted and which was not oxidized. The total air blown divided by the required air per pound of carbon gives the maximum carbon which could possibly have been oxidized:

$$1,818,382,390 \text{ cu. ft.} \div 72.8 \text{ cu. ft.} = 24,977,780 \text{ lbs. C.}$$

Having previously deducted the flue dust loss and the carbon of the iron, the remaining carbon minus the carbon which the air blown actually oxidized, leaves the carbon lost before it reached the tuyeres, or the "solution loss":

$$29,038,000 \text{ lbs.} - 24,977,780 \text{ lbs.} \div 2000 \text{ lbs.} = 2,030.1 \text{ tons.}$$

The percentages of the carbon losses were:

$$2,030.1 \text{ tons} \div 15,484 \text{ tons} = 13.1\% \text{ Solution loss}$$

$$135.0 \text{ tons} \div 15,484 \text{ tons} = .9\% \text{ Flue dust loss}$$

$$830.0 \text{ tons} \div 15,484 \text{ tons} = 5.4\% \text{ Iron carburization}$$

The total percentage of carbon lost, 19.4 per cent C.

Actual Air Calculation

The total air blown as calculated, divided by the total minutes the furnace was in blast, gives the cubic feet of air delivered per minute:

$$1,818,382,390 \text{ cu. ft.} \div 41,806 \text{ min.} = 43,495 \text{ cu. ft. per min. at } 40 \text{ deg. F.}$$

The mean air volume for the month as obtained from the displacement ability of the blowing engines, 383 cu. ft. per revolution at 60 deg. F., corrected for temperature was, 46,306 cu. ft. per min. The difference between the actual air delivered and that blown was the air loss:

$$46,306 \text{ cu. ft.} - 43,495 \text{ cu. ft.} = 2,811 \text{ cu. ft. per min. loss}$$

$$2,811 \text{ cu. ft.} \div 46,306 \text{ cu. ft.} = 6.1 \text{ per cent air loss.}$$

Some reference has been made to authorities, a list of whom, together with the several sources which were consulted in the writing of this study:

M. L. Gruener, "Studies of Blast Furnace Phenomena," a translation by L. D. B. Gordon.

I. Lowthian Bell, "Chemical Phenomena of Iron Smelting."

H. W. Linhardt, a personal communication.

Kinney, Perrott, and Royster, the various experimental data issues of the Minnesota Bureau of Mines.

Bradley Stoughton, "Metallurgy of Iron and Steel."

Robert Forsythe, "The Blast Furnace and the Manufacture of Pig Iron."

The forty-sixth annual banquet of the Engineers' Society of Western Pennsylvania, recently held in the William Penn Hotel, Pittsburgh, Pa., was a real success in every particular. About 1,200 members and guests were present and, as the space provided could accommodate no more, it was a capacity gathering. Engineers were present, not only from Pittsburgh, but from many other cities.

The principal speakers were Stricklemd Gillilan, Merlin Aylesworth, president of the National Broadcasting Company, and Dr. Thomas H. Reed, of the University of Michigan. Mr. Gillilan's talk was of a humorous nature and was very well received. He reached his hearers with a style of humor which was very appealing. In Mr. Aylesworth's discourse he paid tribute to the city of Pittsburgh, which he termed "the pioneer city from which the first trail was blazed for a nation-wide broadcasting service." He referred here to station KDKA of the Westinghouse Company. Mr. Aylesworth described the growth of broadcasting from its infancy and enlarged somewhat on various technical features, such as the transmission of a half-tone photograph by radio in two minutes.

Dr. Thomas H. Reed presented a most interesting forecast of the development of the city of Pittsburgh. He directed the attention of his audience to the transportation facilities of the present day, comparing our modern cities with "the type of cities our English ancestors knew in the days when our ideas of rigid units of local government were created." Mr. Reed cited the fact that "the Borough of Manhattan has actually lost one-sixth of its population in six years and is no longer, in population, the premier borough of New York. It means that the population (of our cities) is spilling out of the center over an enormous area. The same thing is going to happen to Pittsburgh." Doctor Reed further stated, "Human engineering, after all, is the most difficult of all engineering—and as successive generations of Pittsburgh engineers move in, that will be the history of this community."

ANNOUNCEMENT

THE attention of our readers is called to a change in the management of the Andresen Company, publishers of "The Blast Furnace and Steel Plant," "Forging-Stamping-Heat Treating," and the Iron and Steel Directory, effective February 15, 1927.

Mr. Donald N. Watkins assumes the presidency of the Andresen Company and the editorship of "The Blast Furnace and Steel Plant" magazine, and Mr. Charles Longenecker becomes managing editor of the company's publications.

Mr. Watkins, the president, is well known to many of the readers of "The Blast Furnace and Steel Plant," as he was editor of this magazine from 1920 to 1922. Previous to, and after leaving this position, he was superintendent of the blooming mills at the South Side Works of the Jones & Laughlin Steel Corporation. During the past two years, Mr. Watkins has been sales manager for the General Refractories Company in Cleveland and Detroit. He returns to "The Blast Furnace and Steel Plant" with considerable increased experience in these two operating and engineering phases of the steel industry, now covered by the Andresen Company publications.

Mr. Longenecker, managing editor, has had many years experience in iron and steel practice. At the Franklin plant of the Cambria Steel Company, Mr. Longenecker was assistant superintendent of open hearth and later superintendent of open hearth and blooming mills at the Colonial Steel Company. As a combustion engineer, he is well known in both the steel and forging industries.

It shall be the aim of "The Blast Furnace and Steel Plant" to place before its readers material of a live and constructive nature, and such as will be helpful to them in meeting the problems daily arising.

Selection of Motors and Controllers

The Many Factors Which Contribute to the Selection of Appropriate Electrical Equipment Treated in Comprehensive Manner—Motor Characteristics Analyzed

By GORDON FOX*

IT is not possible to cover fully the entire subjects of selection and of application of electric motors and control in brief form. It is purposed, however, to summarize the pertinent facts concerning motors and controls, to outline the factors affecting their application and to indicate a procedure which will apply in some measure in the selection of proper drive apparatus.

Electric motor drive offers great possibilities toward deriving the most effective use of machinery. But very often the full possibilities of a situation are not realized. Far too often a "motor" and "starter" are considered merely as adjuncts whereas a drive and control might be arranged as a primary part of a machine to increase its effectiveness and its productivity or controllability or improve its reliability by affording proper protection. The full advantage of motor drive may be largely missed through scantily considered selection and application. When selecting electric drive equipment a true sense of proportion is a first essential; an evaluation of the importance of the drive and the relation between first cost, operating cost and production value; an appreciation of interruption losses or other shortcomings. Many a dollar of first cost saved has cost precious in subsequent operating deficiencies. Conversely, many a dollar has been spent unwisely.

Elements of Selection

The proper selection and application of electric drive equipment requires:

Knowledge of the purpose, the action and the requirements of the driven machine and the nature of its power demands.

Knowledge of the characteristics, the performance and the costs of motor and control types which may be employed.

Consideration of all factors influencing the application, both general and special to the individual case.

Correct application comprises a proper co-ordination, matching-up and compromising of requirements and apparatus.

Procedure in the selection of motors will be considered under the general headings:

- Group vs. individual drive.
- Electric system or kind of current.
- Specific type of motor.
- Determination of size.
- Determination of mechanical type.
- Enclosure or protection.
- Cost considerations.
- Miscellaneous factors.

Individual vs. Group Drive

In many cases the need for individual drive is obvious, notably for machines requiring large powers, for machines which are isolated and for machines requiring specific features of electrical controllability

or performance. The exclusive use of individual drives is not warranted, however, as group drives have a legitimate field, particularly for machines of lesser powers, which are naturally more or less grouped in location and associated in function and which do not require special control features.

The advantages generally attributed to individual and to group drives respectively are summarized in tabular form for quick comparison. The following comment is explanatory of this summary.

Individual motors driving directly with a minimum of mechanical transmission devices maintain the speed of the driven machine closely eliminating belt slip, a factor which may be of great importance, particularly in connection with very high speed or very low speed machinery. Where production is directly dependent upon maintained speed, the loss of production due to belt slippage will likely render the use of group drive inadvisable.

Where reversal of rotation, speed control or other manipulation or automatic features are desired, the need for individual drive is general.

First Cost

In general it will be found that group drive involves a lower first cost. Because of the diversity of loads of the several machines, a group motor need have a horsepower capacity usually about one fourth to one third of the combined horsepower of individual motors for the same lot of machines. The cost per horsepower of the larger group motor is generally less than that of the smaller individual motors and the cost of a single control equipment is much less than the cost of the many controls required for individual drives. Moreover, because of the lesser number of motors and less special requirements, group drive motors lend themselves to standardization, permitting a minimum investment in spare parts with a maximum of protection therefrom.

Counter to the saving in the cost of the electrical installation is the investment in shafting, belting and mechanical drive accessories, not omitting belt guards, which are often expensive. If the building must be strengthened or specially constructed to carry the mechanical transmission, this item of cost must be recognized.

The question of relative first costs is one which cannot well be generalized. It must be fairly determined in each individual case.

Individual drives afford self contained units which may be located purely with reference to manufacturing needs and with no restrictions because of the drive. They introduce no overhead obstruction and permit of free access by cranes. These factors alone very commonly warrant the use of individual drives.

Power Consumption

Losses in shafting and belting are usually on the order of 10 to 20 per cent of the power transmitted, depending upon the layout, the extent of the trans-

*The Freyn Engineering Company.

mission and the condition of the equipment. This loss is continuous and is largely independent of the machine load, a most significant fact if the machines served are more or less intermittent in operation. The larger motors used for group driving will usually have a slightly higher efficiency than the smaller individual drive motors. Moreover, as the group drive motor will, in general, be more fully loaded than individual motors which commonly run light or underloaded more or less, the group motor will operate more efficiently. The better loading of the group motor will lead to a higher power factor. This will decrease the losses in transformation and distribution and may affect the power rate. Synchronous motors may be feasible for group drives, further benefitting the power factor.

Because of the several considerations involved, a general statement cannot be made as to relative power cost with individual and group drives. The writer believes that, in the majority of cases, the individual drive arrangement will prove more economical of power because of elimination of transmission losses and because the motors and machines need be run only when needed, with no continuous standby losses.

A machine adapted for group drive is commonly belted. The belt conveys power and motion to the machine, but affords no control. Tight and loose pulleys, clutches, change gears, reversing provisions may need to be incorporated in the driven machine to afford necessary controllability. The use of individual motor drive together with suitable control will often lead to marked mechanical simplification of the driven machine, resulting in decreased first cost, lesser upkeep and better performance.

Group drive motors ordinarily run steadily with little starting and stopping; they are rather uniformly loaded and seldom severely overloaded. They are large enough to have substantial parts. They require simple controllers which are not commonly abused. Ordinarily they receive frequent inspection and good

care. For these several reasons group motors and control cause few delays and they have relatively low maintenance cost.

Individual motors are often small using light wires and other members. Often they are of high speeds. They are subject to frequent starts, stops and reversals and to speed adjustments. Not infrequently they are severely overloaded when a driven machine performs some exceptional task. They have a multiplicity of control in the hands of unskilled attendants. They are likely to be more or less exposed. Because of their multiplicity and small size they do not commonly receive as much attention as a group motor receives. For these reasons an installation of individual drives will ordinarily have an electrical maintenance cost two to four times that of a corresponding group drive.

On the other hand, individual drive decreases the cost of mechanical maintenance and replacements of belts, shafting and bearings. Here again specific cases will vary. The writer believes that, more commonly, the total cost of maintenance and replacements will be somewhat higher with individual drive.

For the same reasons above stated there will be less delays from electric motor and control troubles with group drive than with individual drive. Group motors may be well protected with spares. On the other hand, with individual drive faults are confined because of the independence of units. Delays because of belt and transmission troubles are eliminated. Shut downs are less serious.

The remaining factors mentioned in the tabular comparison need no further explanation. Any study must attempt to evaluate these factors for the particular case in hand as the basis for a proper decision. Most important of all, however, is the matter of performance. Individual drive may be fully warranted, in spite of possible higher first cost, higher power cost and higher maintenance cost, provided sufficient advantage to production is gained.

TABLE I—SUMMARIZED COMPARISON OF INDIVIDUAL AND GROUP DRIVE ADVANTAGES

INDIVIDUAL DRIVE	GROUP DRIVE
Maximum production because of maintained speed at machine coupled with most effective control and adjustment of speed to requirements of the work.	
Elimination of shafting, belting, belt guards and accessories. Lighter construction of building may be possible.	Lower first cost of motors and control equipment, due in part to lesser connected horsepower.
Freedom of location and movement of machines.	Greater standardization of electrical equipment possible.
No overhead obstructions, giving crane access.	Lower cost of electrical spare parts.
Lower power consumption because of elimination of transmission losses.	Larger motors have higher efficiencies, particularly as they are operated under load most of the time.
Power consumption in proportion to machines operated. Idle machines may be shut off.	
Simplification of driven machines.	Higher power factor because motors are loaded and because synchronous motors may be used.
Lower mechanical maintenance cost.	Lower electrical maintenance cost.
Independence of drives renders extensive shut downs improbable.	
Less frequent delays from mechanical causes.	Less frequent delays from electrical causes.
Driven machines are protected by limited power of individual motors equipped with overload devices.	Group drive motor has power reserve because of diversity factor.
Greater safety through elimination of belting, ease of control and use of automatic protection.	
Greater cleanliness and better light.	

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In numerous cases it has proven advantageous to carry the individual drive to the extent of a subdivision of mechanisms of a single machine with an individual motor applied to each element. This arrangement results in a simplification of the driven machine, together with better controllability of the individual functions.

In some cases it has proven advantageous to provide two motors to drive a single machine, as for instance one larger motor for driving a pump at full speed and a smaller motor for driving it at a lower speed. Sometimes an auxiliary motor is used to provide slow speed operation for setting-up purposes.

Electric Power System

The broadest classification of motors may be made with reference to the electric system, namely d.c., polyphase a.c. and single phase a.c. The use of single phase motors is largely restricted to applications where this type of service is most readily available, notably for the smaller sizes, 15 hp. and below. Further comparisons refer to d.c. and polyphase a.c. motors.

Where but one kind of power is available, it is obviously desirable, in general, to give preference to motor types adopted for use directly on the available system. This is by no means universally true, however, and conversion of current is quite frequently warranted.

For continuous running constant speed drives both a.c. and d.c. motors may be obtained giving closely parallel performance. For most other classes of service the characteristics available with a.c. motors differ to a greater or lesser degree from the characteristics available with d.c. motors. Induction motors are inherently single speed machines and are restricted to rather definite synchronous speeds. D.c. motors may be designed for any speed desired, speed characteristics can be varied and speeds can be readily adjusted over a wide range. In general the d.c. motor offers a much wider selection of inherent performance characteristics and greater possibilities for flexibility in control. D.c. magnetic control is often more simple and is more highly developed than that for a.c. duty. There is a distinct field, where adaptability and controllability are of first importance, where d.c. is usually warranted and to be preferred. The extensive use of a.c. motors is due primarily to the fact that power is more commonly available in that form. For like reason the induction motor and synchronous motor are being constantly improved. But the d.c. motor continues to hold a well deserved preference for many specific purposes. Each type has its legitimate fields. The proper decision depends upon the requirements of the particular case.

The system upon which motors are to be connected is usually already in existence and determines largely such questions as voltage and frequency. In the development of new plants there may be a choice. With reference to frequency it may be said that, even though power is independently generated, the established and prevailing utility frequency in the district should be adopted. The future, if not the present, may give rise to such needs as breakdown service, extensions or parallel operation. The way should be left open by adoption of the common frequency. In general 60 cycles is to be preferred. Induction motors for this frequency afford a wide and excellent selection of speeds. They are smaller, lighter and cheaper than 25 cycle motors and equal or superior in performance

except in the case of slow speed motors. All slow speed induction motors have low power factor. The 60-cycle induction motor is particularly poor in this respect because of the large number of poles and the higher magnetizing current required.

Choice of Voltage

The choice of voltage for d.c. systems rests between 115,230 and 500 volts. The lower voltage is satisfactory in operating features, but involves heavy copper for distribution without excess voltage drop. The 550-volt motor tends to be a little "touchy." Its commutation is more likely to be imperfect. It is more dangerous. Small motors, shunt fields, control magnets, brake coils, all involve the use of very fine wire which is consequently subject to breakage. On systems where plugging is practiced, pressures of 1000 volts or more may arise due to the addition of motor voltage to system voltage. Two hundred and thirty volts prevails and is more nearly standard. Motors and control for this voltage are most highly developed, lower in price and quicker in delivery. For these reasons it may be recommended that preference be given to 230 volts for general industrial service, compromising the disadvantages of both lower and higher voltage systems. The principle advantage of 500 volts is the economy in distribution. Industrial distribution distances are short. The advent of the automatic substation may make them shorter. The greater safety and reliability and lower first cost and maintenance cost of 230 volt apparatus fully warrants the slight additional distribution expense.

Alternating current motors are standard for 110-220-440-550-2200 and 6600 volts. Single-phase motors are usually wound for 110 or 220 volts for connection to lighting service wires. Industrial systems are usually 220 or 440 volts. The lower voltage is preferred by some on the score of safety. Where motors of small size alone are involved and where distances are short, the 220 volt system is probably preferable. Where larger motors, above 25 hp., are involved and where transmission distances are considerable, the use of 440 volts offers advantages in distribution economy with equal reliability. Control equipment is also cheaper, in some cases, due to the lesser current handled. Static condensers for power factor correction cost half as much for 440 volts as for 220 volts. Motors for 110, 220, 440 and 550 volts all have the same insulation and may often be changed from one voltage to another by changing the end connections. Motors for 2200 and 660 volt service are more heavily insulated. Motors for these voltages may be had in sizes as low as 25 hp., the small sizes being used for power house and substation auxiliaries. The principal advantage of the high voltage motor is the avoidance of step down transformation with its attendant costs and losses. The saving in transformers is partially offset by the higher cost of the high voltage motor and control equipment. For general industrial service high voltages are not to be recommended for motors below 100 hp. High voltage motors should be used only when not unduly exposed and when both motor and control may be properly protected. The use of the lower voltages may be dictated, in some cases, only to gain advantages of greater simplicity, lower cost and better performance of the control.

Choice of Phase

The great majority of a.c. systems and motors are now three phase. Where two-phase alone is avail-

able its use is generally warranted. Some of the more special and recent types of a.c. motors, such as multi-speed and brush shifting types, are not available for two phase circuits. Phase transformations are then necessary.

Direct-current motors may be broadly classified as to speed characteristic, as constant, adjustable and varying speed types. Constant and adjustable speed motors are commonly shunt-wound. Varying speed motors are compound or series wound.

The Shunt Motor

The shunt-wound motor is the prevailing type. This motor has a constant speed characteristic and is well suited for the majority of constant running machines, particularly where the load is of a generally uniform character. The standard shunt-interpole motor is susceptible to speed adjustment by field rheostat to about 115 per cent of its speed rating; often more than this is permissible, if desired, particularly with the lower speed ratings. The adjustable speed motor is, in most cases, of the shunt-wound type, giving a maintained speed at any rheostat setting over its range.

The Compound Motor

The compound-wound motor is more or less a special purpose motor. The additional complexity of the field winding must be justified by a particular need. The compound motor is applied particularly:

To secure high starting torque per ampere input. Required particularly for hard starting or high inertia machines or for starting small motors without accelerating resistance in circuit.

To obtain a drooping speed characteristic, as for flywheel applications.

Where voltage is subject to fluctuations the compound winding tends to improve speed regulation and commutation, particularly with drives having considerable inertia. Adapted, for instance on mine or electric railway distribution systems.

Where load increases rapidly with speed the compound motor may be used to protect itself through its drooping speed characteristic. For instance, in driving a centrifugal fan.

Where a series characteristic is desired, as in service involving starting, stopping and reversing, yet where it is desired not to exceed a stated speed when running lightly loaded.

Where a slow-down is desired in connection with constant speed running, the addition of a series field to a shunt motor renders the slow-down more effective.

Where a series characteristic is desired, in connection with dynamic braking.

Where motors are to be operated in parallel, requiring a drooping speed characteristic.

Compound-wound motors are almost always cumulative, that is, with the shunt and series fields acting in common. The degree of compounding varies. The standard general purpose type of compound wound motor has a no load speed about 115 to 125 per cent of full-load speed. Elevator motors are similarly compounded. Mill type motors with compound windings, have no load speeds 150 per cent to 200 per cent of full-load speed. The latter class, in which the shunt field winding is relatively light, are often termed series shunt motors. Here the shunt winding commonly serves the single function of restricting the light-load

speed. This shunt-field is too weak for effective dynamic braking duty.

The Series Motor

The predominant characteristic of the series motor are, slow speed and high torque on heavy loads with speed increasing under lighter demands. This characteristic fits this type of motor particularly for duty involving frequent and severe starting or reversing and in general where high torques are necessary. Rail-way and crane motors are largely series wound. Mill type motors are commonly so. The series motor has a measure of advantage in that its field coils are made up of heavy wire or strap, minimizing troubles at this point. The series motor has preference over the shunt

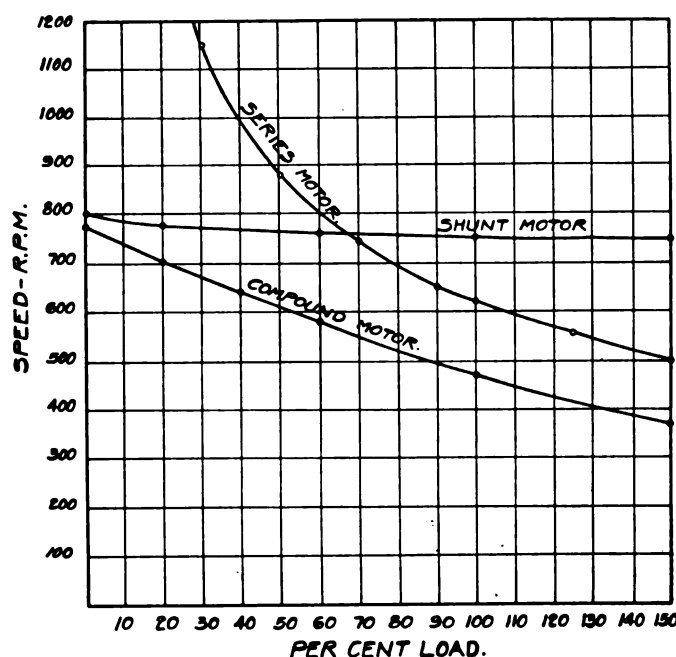


FIG. 1- TYPICAL SPEED LOAD CHARACTERISTICS OF SHUNT-COMPOUND-AND SERIES-WOUND MOTORS.

or compound motor in some duty where collectors are involved since a minimum number of collector rails or bars are required and there is no danger of excess speed due to interruption of the field circuit. The inverse speed characteristic of the series motor is of value in crane service in that heavy loads are necessarily handled at low speeds whereas the crane will make its light trips at a much faster rate. The series motor is used quite extensively in small sizes for starting without resistance, particularly where the load will naturally restrict the speed closely, as for fan drives. Series motors will run away if all load is removed, therefore they should not be used for belted drives nor where the load may be removed through a clutch or other device. As the speed varies with and depends upon the load, the rated full load speed is merely nominal. The actual load in each case must be determined and used as a basis for computation of motor speed and resulting machine speed.

Typical speed-load characteristic curves of shunt, compound and series motors are shown in Fig. 1. The shunt motor characteristic is that of a general purpose motor rated at 50 hp. 750 rpm. The compound-wound motor characteristic is that of a 200 hp., 475 rpm. general purpose motor with moderate compounding. The series motor characteristic is that of a mill type motor rated at 15 hp. 600 rpm.

the secondary circuit. Such motors afford a speed range from about 30 per cent above to 30 per cent below synchronism, with constant speed or drooping regulation as desired, at any setting. The wound-rotor motor is also employed to a very limited extent in cascade with another induction motor to give a selection of speeds.

This type of motor, as now commercially produced, has a stator winding equivalent to that of any other induction motor. The rotor has a high resistance

squirrel cage winding which functions alone during the starting interval and gives the motor a high starting torque, diminishing as the speed increases. When the motor attains a partial speed a low resistance phase winding is given effect by the closure of a centrifugally operated three-point switch which short circuits this low resistance winding. This motor will develop a static torque comparable to that of the wound-rotor induction motor and with low current inrush. Since the secondary resistance is cut out in

TABLE II—MOTOR SELECTION CHART

Type of Motor	Speed Characteristic	Starting Duty	Maximum Torque	Remarks
Direct-current:				
Shunt-wound	Constant Regulation close Speed of slow-speed motors can be increased 25 per cent by field control	Medium	Limited by commutation	Suitable for constant speed drives involving no special conditions
Compound-wound	Fairly constant Regulation about 25 per cent	Heavy	Limited by commutation Greater than shunt motor	For heavy starting duty, widely fluctuating loads, flywheel loads, special control features
Series-wound	Varying Wide speed regulation Must be geared to load	Very heavy	Limited by commutation Can develop very high torque at low speeds	For heavy and frequent starting or manipulating duty where constant speed running not required
Adjustable speed	Constant at selected value Close regulation at any speed Maximum ratio 4 to 1	Medium	Limited by commutation Greater at low speeds	For all work requiring adjustable speeds and constant running at any speed (occasional exception shunt motor with armature control)
Standard squirrel-cage induction	Constant Regulation about 4 per cent	Medium	175 to 250 per cent	Simple, rugged, cheap, widely used; suitable for constant speed drives having no special conditions; poor power factor, especially at light loads and for slow speed motors
High-resistance squirrel-cage induction	Fairly constant Regulation 12 to 15 per cent	Heavy but at not too frequent intervals	250 per cent	Especially desirable for use with flywheel to care for peak loads; can be used where starting duty heavy for standard motor, as for elevator service
Double squirrel-cage induction	Constant Regulation close	Heavy but at not too frequent intervals	200 per cent	Suitable for starting on full voltage with moderate inrush and good torque; efficiency and power factor lower than standard motor
Wound-rotor induction	Constant or adjustable—varying, depending on control used Regulation close at full speed	Heavy, dependent upon control	175 to 250 per cent	Used where frequent or heavy starting is required, where low starting current is imperative or where adjustable-varying speed is desired; cost greater than squirrel-cage
Synchronous	Constant Regulation determined by frequency	Light and medium; not too frequent	Depend on excitation	Used for constant speed drives infrequently started where starting duty is moderate; high power factor; high efficiency, relatively advantageous at low speeds; first cost greater at high speeds
Multispeed	Squirrel-cage, constant Wound-rotor, constant or adjustable varying	Medium	200 per cent	Available in constant h.p. and constant torque ratings; speed ratios 2:1, 3:1, 4:1; suitable where fixed selected speeds suffice
Brush-shifting	Shunt characteristic, close regulation over 3 to 1 range Series characteristic, adjustable varying speed	Medium	150 to 200 at low speed 300 at high speed	High first cost; suitable where adjustable speed characteristic required with a.c. motor and where first cost is warranted

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a single step the torque cannot be maintained throughout the acceleration as well as in a wound-rotor motor. In other performance characteristics it is comparable to the squirrel cage motor. It is started by connecting the primary winding across full voltage. Largely because of the simplicity of the control it is lower in cost than either an equivalent wound-rotor induction motor or a squirrel-cage motor with reduced voltage starter.

This type of motor is particularly adapted for constant speed, constant running drives requiring high starting torque or low current inrush or both. It is especially recommended for small and moderate sizes as a possible means of avoiding both the wound-rotor motor and the oversize squirrel cage motor. The former may well be avoided because of high cost and the latter because of its low power factor. This type of motor may well be considered wherever there may be an urge to install a squirrel cage motor liberally sized primarily to insure satisfactory starting performance under all conditions.

The Multispeed Motor

The multispeed motor is a special type of induction motor having the primary windings arranged to give two or more pole groupings for two or more different synchronous speeds. The secondary may be either cage type or phase wound. The cage type is to be preferred because of its simplicity. Multispeed motors may be rated to develop the same horsepower at different speeds or to develop constant torque, with a higher horsepower rating at the higher speed. The characteristics of the load must be considered in suiting the rating to the application. The more common speed ratios are 2 to 1, 3 to 1, and 4 to 1, although higher ratios are occasional. Motors having a 2 to 1 speed ratio have but a single stator winding, the connections of which are changed to afford two speeds. This type of motor is inherently little more expensive than a single speed motor and the performance on high speed is comparable. Motors with other speed ratios must have two stator windings. This adds to their cost and causes the power factor to be rather low, particularly at the lower speed. The multispeed motor finds a number of applications where two running speeds will suffice in lieu of adjustable speed drive. It is also meeting with some favor for semi-manipulating service, for instance on elevators and skip hoists, where the high speed is used for running and the low speed for making landings. The high resistance cage is used in some of these applications. In the absence of an adjustable speed a.c. motor there appears to be a tendency toward further development and application of the multispeed motor particularly for special applications.

New Electric Drive Installed

The largest steel plant in the west, that of the Colorado Fuel & Iron Company, Pueblo, Colo., has now started operation with its new electrical equipment. This company recently made a complete change-over from steam to electric drive (with the exception of its blooming mills), using electricity generated on the premises in the largest industrial power plant in the Rocky Mountain region.

The company was incorporated in 1892 and, until a few years ago, all power used in the plant was derived from steam engines. Electrification was first

considered during the period following the war, and the initial program included a power plant, the electrification of the rod and 10-inch mill, the 14-inch mill and the rail mill.

All the main electrical equipment, including the turbine generators in the power house, was furnished by the General Electric Company. Among the items are three 10,000-kw. turbine generators to furnish power for the various mills, and two 1,000-kw. motor generators to furnish direct current to the power house and the adjacent mills.

An outstanding feature of the fuel supply is blast furnace gas cleaned by electric precipitators. Powdered coal is used as a standby fuel. The reduced steam requirements resulting from electrification, together with the more efficient use of blast furnace gas, has resulted in shutting down approximately 85 per cent of a boiler plant containing 30 500-hp., hand-fired boilers.

The switch house contains three buses, one main 6,600-volt bus for supplying large blocks of power to the various mills, an auxiliary 6,600-volt bus for supplying smaller blocks of power to various outlying operations, and a 2,300-volt auxiliary bus for the power house auxiliaries. All power leaves the power house at 6,600 volts, as generated and as used by all the large a.c. motors.

The rod and 10-inch mills, the first in operation, are located in the same building and use the same billet heating furnaces and continuous mill. This mill was originally driven by four reciprocating engines, now replaced by two 3,000-hp., slip-ring, induction motors; two 1,000-hp. motors of the same type; two 1,500-hp., d.c. adjustable speed motors, and a 300-hp. motor of the same type. One of the 1500-hp. motors, located in a separate motor room, is supplied by a 1600-kw. synchronous converter also located in the same room. The other 1500-hp. and the 300-hp. motor, located in the main engine room, are supplied by another synchronous converter of 1600 kw. capacity. All the a.c. motors drive the stands through reduction gears, whereas the d.c. motors are direct connected.

The 14-inch merchant mill was originally driven by a single engine connected to the continuous stands with rope drives connecting the intermediate and finishing stands. This was replaced by a 1500-hp., d.c. adjustable speed motor connected directly to the intermediate stands with a rope drive to the continuous stands, and a similar 750-hp. motor directly connected to the finishing stands. A 1600-kw. synchronous converter, a duplicate of the two in the rod and 10-inch mills, supplies power to these two motors.

The rail mill was formerly driven by an engine on the roughing stand and a second engine on the intermediate and finishing stands. These two engines were replaced by a 2,000-hp., a.c., slip-ring, induction motor on the roughing stands and a similar 3,000-hp. motor on the intermediate stands. The finishing stand was separated from the intermediate, and a 1200-hp., a.c., slip-ring motor now drives this stand. All these motors drive the mills through reduction gears, and in the case of the roughing and intermediate stands, the original engine flywheels were mounted on new bearings and connected to the mill side of the reduction gears. Permanent resistance is inserted in the secondary of these motors to take advantage of the fly-wheel effect.

Large economies are expected in power, labor and maintenance by the electrification.

The Centrifugal Casting of Steel*

The Two Methods by Which This Process May Be Carried Out
Explained—Molds Heated and Filled While Spinning in
Horizontal Position—Substantial Saving Claimed

By LEON CAMMEN†

IN speaking of centrifugal casting of steel a clear distinction must be made between the more or less well-known art of centrifugal casting of pipes or tubes and the new art of centrifugal casting of bars. The purpose of the former is plain. The casting of bars is for the purpose of rolling them into such products as sheet bars, plate bars, wire rod, rails, structural material, plate and the like. This is a comparatively new departure and more will be said about it later.

While centrifugal casting is done to a small extent on a vertical and inclined axis, the usual way is by introducing molten metal into a mold spinning on a horizontal axis. This is comparatively simple when dealing with such a metal as cast iron, because temperature conditions there are suitable and the metal can be superheated if necessary.

With steel, whether plain carbon or alloy, several complicating factors have to be taken into consideration. For many reasons it is not desirable to cast superheated steel, and in fact, the best castings are obtained from comparatively cold metal. This, combined with the rapidity with which steel chills, makes its delivery through long spouts impossible except where very large amounts of metal are involved. It becomes, therefore, necessary to use a comparatively short spout and this, with cold molds, limits the length of the mold, and hence the casting. Longer castings can be obtained by using a hot mold, at the expense, however, of additional trouble and cost of heating and handling the mold.

There is another feature, applying particularly to steel and special ferrous alloys of low carbon content, which also contributes to the necessity for using a very hot mold in centrifugal tube casting (in this connection attention must be called to the fact that the present part of the paper deals exclusively with tube casting, as conditions are entirely different in the newly developed art of centrifugal bar casting). Assume that we are casting a steel tube, to be used as a hollow blank for a seamless tube mill, 8 ft. long, 10 in. outside diameter and 7.5 in. inside diameter. The weight of metal in such a tube is so large that, with a spout extending into the mold for a distance of, say, 4 ft., there is no trouble to deliver metal in such a manner that a tube of uniform thickness from end to end will be formed even when the temperature of the mold is only 350 deg. F. This does not mean, however, that the tube will be good. As the first metal is delivered against the fairly cold wall of the mold, it

forms a thin tubular shell which immediately contracts on cooling, with the result that the cast tube lies loosely in the mold. This condition is aggravated still more by the fact that the mold, heated by the contact with the very hot metal, expands. The result of the combination of these two conditions is that the cast tube, while subject to centrifugal stresses in the process of its formation, receives no support from the mold. The centrifugal stresses in this

case are fairly large, 75 to 100 lbs. per lb. of metal cast, while the mechanical strength of the shell of a centrifugally cast tube, with molten metal all the time coming on top of it, is naturally low, and cracking of the tube results.

The above explains why tubes cast in cold molds as a rule crack longitudinally and not circumferentially. The centrifugal stresses in a tube in the process of being cast are essentially the same as those produced by water pressure in a cylinder, and it is common knowledge that this is why cylindrical boilers are usually single-riveted in the circumferential seams and double or triple riveted

in the longitudinal seams.

This cracking does not occur as frequently in casting in a highly heated mold, first because the casting does not contract away from the mold until after the spinning has ceased, and second, because the mold itself is so hot that contact with the cast tube does not produce expansion to any material extent.

Commercial Possibilities of Centrifugal Tube Casting

From a commercial point of view a distinction should be made between centrifugal tube casting in metals which can be pierced and metals which cannot. Where the metal cannot be pierced, as is, for example, the case with certain chromium and manganese alloy steels, centrifugal casting appears to be one of the few possible solutions of the problem, very likely the best, and there the question is not so much making the casting at a cost, as producing a hollow billet at all. It is believed that under these conditions centrifugal casting has a bright and promising future. Short or heavy wall tubes can be made in what may be referred to as cold molds and tubes of very considerable lengths in molds heated to the proper temperature. More about this question of temperature will be said later.

Where the metal can be pierced, the commercial value of centrifugal tube casting becomes less certain. Only one tube at a time can be cast in a centrifugal casting machine, which means that for each tube there is a considerable amount of handling. Judging from

One of the most interesting subjects before open hearth men today is the casting of ingots. At many plants experiments are now being carried out with improvement of practice as the objective, for as specifications become more stringent, practice must be improved. Interest has also been aroused in this important feature by the necessity of providing ingots of the highest quality for conversion into tubes. Appreciating the demand for information bearing on this subject, the accompanying treatises, covering two phases of steel casting, are offered our readers.

—Editor.

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the practice in centrifugal casting of cast iron pipe, most of the operations are manually controlled. Centrifugal casting of cast iron pipe competes with hand-molding, a labor-devouring process, and yet it is quite doubtful whether centrifugal casting costs less than hand-molded pipe. That it costs less to make steel tubing say up to 6 in. by piercing than by casting, is fairly certain. It is only in larger sizes that centrifugal casting begins to loom as a competitor of pierced billets. It is, however, too early to say today which will ultimately prevail, as our experience with piercing large billets on a commercial scale is only a few months old, while centrifugal casting of steel on a large scale is non-existent. Because of this where the billet piercing can be done reliably and comparatively cheaply, the prospect of competition on the part of centrifugal casting of tubes as a starting material for seamless tube manufacture is still uncertain. Emphasis should be made, however, on the reliability of the piercing process. Several companies under pressure of the demand for oil country goods jumped into big seamless tube manufacture. Speaking colloquially, they all claim that the "water is fine." Within a year or so we shall probably know exactly what it costs to pierce a 12-in. billet, and then we may find that with all its disadvantages casting the hollow billet centrifugally, particularly in a hot mold, may prove to be a good deal cheaper than handling it in the mammoth piercing mills of today.

Another application of centrifugal casting which bears material promise is under development now and deals with the casting of tubes of very large diameter, 60 in. and over, to be used for the production of high pressure steam boilers (say 900 lbs. per sq. in. pressure and up).

The Art of Centrifugal Tube Casting

Centrifugal tube casting involves certain mechanical and metallurgical problems. We shall start with the latter. Earnest attention is called to the fact that metallurgically centrifugal tube casting is entirely different from centrifugal bar casting. The general belief that in centrifugal casting all impurities will be thrown out of the metal and delivered to the inside face of the casting in a manner somewhat similar to what occurs in milk separators, is based on an incomplete understanding of facts. This will happen where the impurity is a big lump of clay, say, $\frac{1}{4}$ -in. diameter, and up, but not where we deal with comparatively fine sonims. The viscosity of the metal is so great and the time during which the metal remains liquid and is subject to the action of centrifugal force is so short, that as a rule the finer impurities will be found in that part of the pipe to which they were delivered by the flow of metal.

On the other hand, segregation is materially absent in properly cast tubes which is due to the same causes which prevent the travel of impurities to the inner face, namely, the lack of time for the transfer of sonims and sulphur, phosphorus, silicon, manganese, and carbon compounds, from one part of the cast tube to another. It is, therefore, as important in centrifugal casting to use clean steel, as it is in ordinary casting.

From a mechanical point of view a distinction must be made between casting in a cold mold (which means a mold heated to about 300 to 400 deg. F.) and casting in a hot mold (of the order of 1000 to, say, 1600 deg. F.) In any event the machine must be sub-

stantially built with large factors of safety, set on an extremely solid foundation (the author in his work always uses under the machine a monolithic concrete pad not less than 6 ft. thick) and well balanced. The matter of support of molds in tube machines is a comparatively simple problem. In the case of cold molds, it is sufficient to have the mold, which may be made of steel or cast iron, enclosed in a heavy steel tube and provided with thin (say, $\frac{1}{2}$ -in.) ribs bearing against the outside tube. Where a hot mold is used, the mold should be made only of materials that do not rapidly deteriorate under the action of heat and that do not lose their hardness at the temperature at which the mold is employed.

Hot Molds

Hot molds used in centrifugal tube casting have to be protected from the solvent action of molten steel. This may be done in several ways. Where an extremely low carbon steel is used, a layer of oxide on the internal surface of the mold will be satisfactory. It should not be used, however, where the carbon content exceeds say 0.10 per cent, as there the oxide on the surface of the mold is reduced by the carbon in the steel; gas is formed and as it has no other way to get out except through the metal, blowholes result. These blowholes, by the way have a peculiar shape, somewhat like pears, with the thin end towards the mold.

The mold in centrifugal casting has to be heated to some extent in any event to prevent the presence of moisture on the mold wall. If such moisture is present, it forms, upon contact with molten steel, high pressure steam which expands explosively and in doing so and trying to make for itself a path of escape, forms blowholes on the outer surface of the cast tube. It is advisable, therefore, to have the mold heated to at least 300 deg. F.

Centrifugal bar casting is to all practical purposes a new art. While several attempts have been made to cast bars, gears, etc., in the past, none of these led to satisfactory results and practically all such attempts were usually abandoned after a few trials and without comprehension of the reasons which made the attempt abortive.

Mechanics of Centrifugal Bar Casting

In contradistinction to centrifugal tube casting, centrifugal bar casting permits the handling of large amounts of metal from perhaps 5 to 6 tons for sheet, bar and wire rod molds up to some 30 tons per machine in rail and structural steel billet casting. Because of this a close control can be had on the rate at which molten metal is delivered to the spinning mold. As the first metal comes in it instantly freezes, probably close to the beginning of the partition lugs. The next metal, however, flows a little way over the hot metal previously solidified, rather than over the cold wall, which gives it a chance to reach further out into the mold and really produces an equivalent of the tube casting in a hot mold. In this way from the first metal teemed from the ladle a thin layer is formed the full length of the mold, which may be anywhere from $6\frac{1}{2}$ ft. to 14 ft. and more long. As the next metal comes in, it is flowing over the layer of extremely hot metal which has just solidified. It is important to teem the metal from the ladle into the machine at such a rate that at no time should there be a layer of molten metal present of a thickness

greater than say $\frac{1}{4}$ in. Fig. 1 shows diagrammatically an original solidified layer of metal in immediate contact with the mold, and the next layer thereon which is still molten. As will be made clearer later, the rate of teeming is one of the most vital influences affecting the structure of the cast bars.

Now a continuous process takes place. As more molten metal is added at the top of the layer of molten metal already present, the bottom of this layer solidifies and in this way the thickness of the solid layer is increased while that of the molten layer stays approximately without change. This has several results. In the first place the solidification of the metal proceeds at a fast rate so that roughly not more than 30 to 45 seconds, and possibly much less, elapses between the time the metal leaves the ladle and the time it solidifies in the mold. Compare this with, say, 15 minutes to $\frac{1}{2}$ hour that the same process takes inside of a 3-ton ingot under the usual practice. It is this very great rapidity with which the metal freezes that makes it practically impossible for segregation to take place.

In an ordinary ingot, freezing proceeds in the following way. The shell of the ingot rapidly freezes all around while the central core remains molten for a long time. As the metal freezes it contracts and as the freezing proceeds from the outside of the shell inward, a contraction takes place in the shell while the central part of the ingot is still liquid. When the ingot finally freezes, a series of planes of weakness are formed which in a rectangular ingot are directed roughly along the diagonals of the horizontal section. The larger the ingot the greater and more dangerous are these planes of weakness. Without going into detailed discussion of their origin which is well known, it may be said that the most essential condition for the formation of such planes of weakness in an ingot is availability of time. In centrifugal casting no such time is available, and hence the most important condition is removed, so that "ingotism" becomes impossible. Furthermore, the freezing proceeds in thin layers and the metal while freezing is perfectly free to draw from the molten layer present at its top until the final layer is being formed. Because of all this, centrifugally cast bars have been found to be absolutely free from such planes of weakness as are encountered in stationary ingots.

Elimination of Gases Contained in Molten Metal

When we come to the matter of gases, a somewhat more complicated condition is found to exist. All molten steel contains a certain amount of gases held in solution. As the metal chills, its ability to hold the gases decreases and a liberation of gases takes place. This action is extremely rapid and will take place even during the short period of freezing available in centrifugal bar casting. As the temperature of the bottom of the molten layer decreases from that at which it reached the bar initially to that of freezing, the metal liberates gases which gradually accumulate in the molten layer maintained on top of the bar by flow from the ladle. The ability of this layer to hold the gas in solution is, of course, quite limited, so that after a while a discharge of the gases from the metal into the air takes place and the topmost layer may be considered in the light of a saturated solution of gases in question in the metal. As long as new metal is supplied to the bar this condition will be maintained more or less stationary. It is only when we come to the topmost layer at the end of the casting that we have to consider what happens to the gas dissolved in the

metal. The answer depends on the rate of freezing of the topmost layer and on the velocity of rotation of the machine. If this topmost layer is thin, metal being supplied from the ladle at a comparatively slow rate (more will be said about it later) only a comparatively thin layer of the ultimate metal structure is at best affected by the presence of gases, even should the metal freeze in such a manner as to prevent their

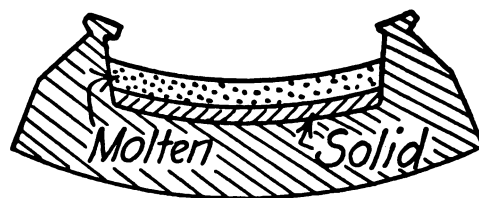


FIG. 1—Sectional view of bar as cast.

possibility of escape. In that layer, however, the gas liberating from the metal may be unable to escape and small blowholes may be formed. The question of speed at which the machine is run becomes of importance here.

In speaking before a body of experts, such as represented by the American Society for Steel Treating, it is unnecessary to explain formation of pipe in an ingot. The recognized theory today is that it is due in part to evolution of gas on freezing, essentially in the manner described above, and in part, to the fact that in an ordinary ingot the external surface solidifies first, and the core last. The volume of the ingot is, therefore, determined on the solidification of the shell and when the core solidifies and contracts it can only do so at the cost of forming a cavity. This can be prevented in part by such methods as hydraulic compression of ingots, which, however, are not applicable to the great majority of steel products. Another method widely resorted to is the use of nozzles or hot tops, but this means only transferring the pipe cavity from one part of an ingot to another. In centrifugally cast bars the same process takes place. As the bottom layer solidifies it contracts and if left alone would form contraction cavities. There is, however, an overlying layer of molten metal powerfully pressed against the solidifying lower layer, and this serves efficiently to fill up contraction cavities. It is only the last layer of metal that has no such source of molten steel to help it out, but here contraction is limited to only a thin strip, probably not more than $\frac{1}{8}$ of an inch, and such contraction cavities as may occur are apparently too small to be noticed. On the other hand, if metal is teemed into the mold too fast, and particularly if too much vibration is present in the mold, the surface is apt to be rough or wavy.

Because of this, in a properly teemed bar, there will be no cavity. Emphasis should be laid, however, on the bar being properly teemed. If the metal is supplied to the mold at an excessively fast rate, a heavy layer of molten metal is present at the end of the teeming. It may (and actually has) happened that the outermost face (i.e., the one toward the inside of the mold) exposed to the cooling action of the air will freeze first, and the inner layer of molten metal next. In such a case contraction cavities will be formed substantially in the same manner as in a stationary ingot. However, instead of lying inside of the ingot, they will all be located at some distance below the inner surface of the bar. This does not make them any more desirable and the greatest attention should be

paid to determining for each size of bar cast, each size of machine, and each speed of machine used, the proper rate of teeming which can be then maintained by using a nozzle of the proper size.

Mechanical and Operating Details

Because of the novelty of the process of centrifugal bar casting something might be said about the details of its application. As stated above, the purpose of centrifugal casting is to provide material for use in rolling or forging. Let us consider the former. Today for rolling, such as, for example, rails, a large ingot is cast, say, 24 x 24 inches in cross section, some 6 feet long. The ingot is then delivered to the soaking pit and thence to the blooming mill, where it is converted into a billet or slab suitable for the production mills (this term will be used henceforth to cover the roughing and finishing mills). The purpose of centrifugal bar casting, on the other hand, is to produce a bar of such a size and character of metal that it would be directly suitable for rolling in the production mills and would give an ultimate product of a quality not inferior to that produced by the ordinary process. This means that the character of the material should be such that the ultimate result would not be affected by the elimination of blooming. The section of the bar should be such as to be directly suitable for use in the production mills and its length should be such as to make the use of production mills economical.

Several considerations are involved here. The first of them is—Why is blooming required today? Tests made some years ago at the Bethlehem Steel Company on fogings have shown that even if the cross section of an ingot is reduced by forging in the ratio of 64 to 1, which is more than any blooming ever did, ingotism is by no means completely eliminated. On the other hand, blooming in present ingot practice is used for excellent reasons. The ingot as cast today has an extremely variable structure, the metal being fine-grained and strong in the shell which freezes first and does it rapidly. It is coarse, pipy and vitiated by planes of weakness in other parts of the ingot, especially the core where freezing is slow and where it proceeds simultaneously with the development of considerable mechanical strains. What blooming does is, by rolling the metal at practically welding temperatures and under enormous pressures, to equalize the structure more or less throughout the body of the metal and to eliminate to a greater or lesser extent the weak spots enumerated above.

Life of Molds

This is an important subject affecting as it does the cost of bars produced by centrifugal casting. It is regrettable, therefore, that not enough information is available to state with authority what the life of the mold would be under given conditions. The rather limited practice in the past has shown that molds are only little affected even when working under the most strenuous conditions. The following should be taken into consideration in this connection. The molds in bar casting machines are extremely heavy, weighing from four to seven times as much as the metal cast, and the cast bars are removed quite rapidly. Because of this, the mold never becomes very hot, and in fact, it is not desired that it should exceed say 500 deg. F. at any time.

The other possible source of trouble lies in the possibility of oxidation of the surface of the mold between castings. It is expected that this will be taken

care of ultimately by depositing upon the surface of the mold some non-scaling material, and experiments made thus far show a good promise of success in this direction. It has been found, however, that this tendency to scale is not great anyway, and a mold will probably stand at least 1000 castings before it has scaled sufficiently to make trouble. When this happens, the partition lugs may be taken out and the mold rebored.

While this feature of the life of the mold has hitherto received only a somewhat sketchy treatment, it must be remembered that the whole art of centrifugal bar casting is only in its infancy. At the same time it should be borne in mind that it has already attracted the attention of some of the most powerful independent steel companies in this country. In a process promising to save some \$3.00 to \$6.00 per ton of steel it would not take long to straighten out such details as protection of the mold against surface scaling. The above estimate of savings is however made for molds not so protected.

Advantages of Centrifugal Bar Casting

The question may be raised as to what are the advantages of centrifugal bar casting as compared with the present method of ingot casting and blooming. Not enough work has been done yet to establish with certainty that centrifugally cast material possesses properties essentially superior to steel well made by the conventional process. It has been found that if the metal is dirty in the ladle, it will be dirty in the casting, so that centrifugal casting is not a cure for poor furnace operation. On the other hand, there is good reason to believe that in properly made centrifugally cast metal segregation will be entirely eliminated or at least greatly reduced. The main value of centrifugal bar casting (and herein it differs materially from centrifugal tube casting) lies however in the stark matter of costs. The reduction of cropping from an average of 12 per cent (running as high as 20 per cent in some special cases, such as rails) to about 2 per cent, and the elimination of the entire blooming operation with all it implies, are equivalent to a reduction in costs of from \$3.00 to as high as \$6.00 per ton on standard products.

The sixteenth annual report of United States Steel and Carnegie Pension Fund shows that in the year 1926 the sum of \$2,537,916.92 was distributed as pensions among retired employees of the United States Steel Corporation and its subsidiary companies. Carnegie Steel Company was first among the subsidiaries in the amount paid to retired employees, the sum being \$615,604.67. Some of the bigger subsidiary companies, and their pension disbursements, were: American Steel & Wire Company, \$557,044.40; American Sheet & Tin Plate Company, \$347,505.32; National Tube Company, \$241,975.87; H. C. Frick Coke Company, \$196,530.59; Illinois Steel Company, \$130,057.27; American Bridge Company, \$120,803.15; Oliver Iron Mining Company, \$105,202.40; Tennessee Coal, Iron & Railroad Company, \$35,802.20; Bessemer & Lake Erie Railroad Company, \$35,033.05; and Elgin, Joliet & Eastern Railway Company, \$28,442.15. There were 1,185 employees added to the pension roll during 1926 and 532 were removed by death. At the close of the year there were 5,737 on the pension roll. The average age of the employees retired in 1926 was 62.79 years; their average period service was 31.57 years.

Solidification of Steel in the Ingot Mold*

Many of the Features Which Differentiate Good and Bad Practice
Are Enumerated and Discussed—Temperature at Which
Metal Is Poured Vital—Type of Mold Important

By ALEXANDER L. FIELD†

THESE may be found in the literature a record of numerous researches and observations on the solidification of steel, considered (1) as a physico-chemical process involving the formation of austenitic solid solution or delta iron from the liquid, with its attendant phenomena of crystal growth and of segregation of dissolved constituents and of nonmetallic inclusions; (2) as a step in the manufacture of ingots or castings in which the transition of a confined mass of liquid steel to a solid of greater density, brought about through cooling of its surface, gives rise to complex problems of pipe formation and its prevention by sinkhead feeding; and (3) as a similar step in manufacture which in the case of "open" and of incompletely "killed" steels is complicated by gas evolution and the occurrence of blow holes. When the independent effects of steel composition, pouring rate, pouring temperature, and mold design are considered also, the exceedingly involved nature of the general subject is apparent.

The present paper does not pretend to treat of the solidification of steel in any extensive manner nor to cover exhaustively any one of its numerous aspects. Rather, it contains certain results of a preliminary search after basic principles underlying the solidification of steel within the mold chamber and its methods, so far as included herein, are entirely mathematical.

General Assumptions

In order to simplify the calculations which follow, steel will be considered as though it were a pure metal, solidifying at a definite temperature instead of through a temperature interval, and no account will be taken of the particular case where gas is evolved during freezing. The material of the mold, which is usually cast iron, will be assumed to possess the same values of thermal conductivity, density, and specific heat displayed by the steel after solidification, or, to be more exact, the same value of thermometric conductivity or diffusivity (thermal conductivity divided by the product of density and specific heat).

Also, it is assumed that contact between the mold wall and the contained steel persists until solidification is completed. Actually, of course, thermal contraction of the ingot shell during its fall to temperatures below the freezing point causes the surface of the steel to withdraw from the wall as soon as the radial component of thermal stress exceeds the ferrostatic pressure.

These particular general assumptions, to the extent by which they fail to represent actual conditions, affect only those calculations below those which have to do with the rate of solidification. They can be dispensed with, if desired, in deriving the equations of the shrinkage cavity.

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In the shrinkage cavity calculations, on the other hand, it is consistently assumed that the top surface of the ingot suffers no loss of heat due to radiation and convection, or, rather, that there is a horizontal surface impervious to heat at the top of the mold chamber. Actually, radiation and convection losses cause the formation of a crust of solid steel over the liquid below. This crust, however, rather effectively retards further heat loss as the development of the shrinkage cavity proceeds beneath it.

Finally, attention is called here to the fact that the effective coefficient of contraction on passing from the liquid to the solid state, which occurs in the shrinkage cavity equations, is not equal to the true coefficient as measured at the melting temperature, but is smaller. This arises from the partial neutralization of the true isothermal contraction at the change of state by the opposing, progressive contraction of the solidified shell. The true coefficient is approximately 0.06, whereas the effective coefficient observed may be around 0.02.

Ingot Solidification versus Isothermal Crystallization

The well known theories relative to crystallization rate are in the main built around the central idea of isothermal conditions. Most frequently they are further restricted to crystallization of a solid from a liquid solvent. The crystallization of sugar from its aqueous solution, either by evaporation or cooling is a complete instance in point. Whether crystallization is initiated from suspended nuclei or from the walls of the container, no appreciable temperature gradient exists within the solution. Where the complete crystallization of a substance has been studied, it has been customary to observe the process as it occurs in containers of capillary dimensions or under other conditions which approach the isothermal one. Tammann and his school in particular have made many valuable contributions, theoretical and experimental, in this field. As far as possible the factors influencing rate of crystallization are reduced to (1) number of available nuclei, (2) degree of supercooling or supersaturation, and (3) the inherent crystallizing power of the substance at the temperature in question.

The rate of solidification of steel in the mold chamber, in sharp contrast to the process conducted as above, is determined entirely by the rate at which heat is conducted away from the liquid metal. The number of available nuclei in the liquid metal and its crystallizing power are more than great enough to provide all the liberated heat of fusion which can escape by thermal conduction.

Maximum Rate of Solidification of Steel in the Mold Chamber

Consider two infinite bodies, one (A) composed of liquid steel at its melting temperature and the other (B) solid steel at room temperature (or mold wall), each with a single plane surface and with these sur-

faces placed suddenly in contact. Heat will flow from (A) to (B) and solidification will proceed in a direction normal to this plane surface.

Let

T_m = initial temperature of (A), degrees C.

T_o = initial temperature of (B), degrees C.

t = time in seconds, measured from the instant of contact of (A) and (B).

L = latent heat of fusion, gram-calories per gram.

k = thermal conductivity, gram-calories per degree C. per square centimeter per centimeter⁻¹.

d = density, grams per cubic centimeter.

s = specific heat, gram-calories per degree C.

v = linear velocity of solidification, centimeters per second.

If W is the quantity of heat liberated by solidification per second for each square centimeter of solidifying surface, then

$$(1) \quad W = Lvd$$

The quantity of heat conducted away from unit surface per second may be calculated by the aid of Fourier's series and is likewise equal to W . The resulting equation is

$$(2) \quad W = \frac{k (T_m - T_o)}{1.77 \left(\frac{kt}{ds} \right)^{.5}}$$

Equating (1) and (2), and transposing.

$$(3) \quad v = \frac{(T_m - T_o)}{1.77 L t^{.5}} \cdot \left(\frac{ks}{d} \right)^{.5}$$

Equation (3) expresses the relation between the maximum velocity of solidification and (1) the difference between the melting temperature of the steel and the initial mold wall temperature, or $(T_m - T_o)$; elapsed time (t) measured from the instant of contact; (3) latent heat of fusion (L) of the steel; and (4) the physical properties of thermal conductivity (k), specific heat (s), and density (d), each with reference to the solid steel. Items (1) and (2) can be measured directly with accuracy. Item (3) is known to be equal to approximately 70. Of the three physical properties grouped under item (4), specific heat only has been determined up to the melting point.

Temperature deg. C.	Specific heat
0	0.105
100	0.117
400	0.151
700	0.185
800	0.159
900	0.159
1000	0.145
1100	0.145
1200	0.145
1400	0.145

The density of solid iron, which is known to be 7.8 at ordinary temperatures, decreases to a value close to 7.4 at its melting temperature. The thermal conductivity of iron at ordinary temperatures is equal to about 0.16 and is known to decrease comparatively rapidly at high temperatures. At the melting temperature this value is probably around 0.05.

Actually, equation (3) holds rigidly only for constant values of k , s , and d . To modify this equation to take care of the variations of these physical properties with temperature over the range T_m to T_o would present mathematical difficulties even if these variations were accurately known in each instance. However, because of the fact that the three symbols occur under the square root sign in equation (3), an error in assigning the proper values affects the value of v to a relatively small degree. Assuming $k = 0.07$, $s = 0.15$, and $d = 7.5$, and substituting in equation (3),

$$(4) \quad v = \frac{(1535 - 35)}{(1.77) (70) t^{.5}} \cdot \left[\frac{(0.07)(0.15)}{7.5} \right]^{.5}$$

$$\text{or } v = 0.44 t^{-.5}.$$

From equation (4) may be calculated the maximum rate of solidification, in a direction normal to the mold wall, at any time.

By simple integration, equation (4) yields the equation governing the relation between total elapsed time and total distance through which solidification has progressed, or

$$(5) \quad D = 0.88 t^{.5}$$

where D is the distance in centimeters, taken normal to the wall of the mold chamber.

From (5) it would appear, for instance, that at the end of the first second solidification cannot have progressed further than 0.88 centimeter, and that at the end of 60 seconds the maximum thickness of solidified steel cannot exceed 7.8 centimeters. The reciprocal of rate of solidification, as well as the thickness of solidified steel, increases parabolically with elapsed time.

Effect of Degree of Superheat Above the Melting Point Upon Solidification Rate

The specific heat of liquid steel in the neighborhood of its freezing point is equal to about 0.15, while the latent heat of fusion is 70. In other words, the heat set free by the solidification of one gram of steel is equal to that abstracted from 467 grams of liquid steel in cooling through one degree within the temperature range above and close to the melting point. It is obvious, therefore, that, if the liquid steel is at a temperature above its melting point when brought into contact with the mold wall, the effect upon rate of solidification is equivalent to substituting for $t^{1/2}$ in equation (4) the expression $(t^{1/2} - t_o^{1/2})$, where t_o is the time which elapses before the liquid steel is cooled to its freezing temperature. (It is assumed, here as elsewhere, that the liquid steel is of uniform temperature throughout). The same applies likewise to thickness of solidified metal and to equation (5). Now if, for instance, the slab of liquid steel in contact with the mold wall has an initial thickness of 25 centimeters and is initially at a temperature of 50 deg. above the melting point, then each square centimeter of the wall must dissipate $25 \times 6.9 \times 0.15 \times 50 = 1,290$ calories before solidification begins. Since the latent heat is 70 calories, a 50-deg. superheat has a time equivalent corresponding to the solidification of

$$\frac{1290}{70} = 18.4$$

grams of steel per square centimeter or to a distance of solidification equal to

$$\frac{18.4}{7.4} = 2.5$$

centimeters. From equation (5) initial solidification through a distance of 2.5 centimeters takes place in 8 seconds.

If, therefore, a 50-deg. superheat is taken, subject to the assumption regarding available volume of liquid steel, it follows that solidification would not begin until the end of 7 seconds and that at the end of the ninth second (the first second of actual solidification) the thickness of metal solidified would be equal to $0.88 (9)^{\frac{1}{2}} - 0.88 (8)^{\frac{1}{2}}$ or to 0.17 centimeters, as against 0.88 centimeters for the first second of solidification for liquid steel initially at its melting temperature. The thickness of solid metal formed in 60 seconds would be 4.9 centimeters as against 7.8.

The very great effect of degree of superheat upon solidification rate is evident from such considerations as the above.

Effect of Mold Wall Thickness Upon Rate of Solidification

In the preceding section a mold wall of infinite thickness was assumed, or a mold wall so thick that the temperature rise on its outer surface is too small appreciably to affect the rate of freezing of the confined liquid. Elementary considerations point to the fact that for the first brief period of solidification the effect of thickness of mold wall is negligible and that all molds of ordinary design should give approximately the same initial rates as would a mold of infinite wall thickness. The effect of mold thickness becomes observable as solidification proceeds and is of increasing importance as solidification nears completion and also as the cross-section of the mold chamber increases.

As a matter of fact, a certain time is required for the rise in temperature of the inner wall to have any effect whatever upon the temperature of the outer mold wall. A certain period must elapse before the heat flow reaches the outer wall. As a result, there is a definite interval of time during which the steel freezes precisely as it would in a mold of infinite wall thickness. This interval is calculable by the aid of Fourier's series. By means of the same device the effect of finite wall thickness upon solidification after the lapse of this time interval may be computed approximately. It is planned to give the results of such calculations in a subsequent paper.

The Equation of the Pipe or Shrinkage Cavity

The derivation of equations which define the shape and location of the pipe or shrinkage cavity as a function mold chamber co-ordinates of the mold chamber, taking the longitudinal ingot axis as the Y-axis and the basal plane as the XZ-plane.

Mathematically, the simplest case (Case I) is that of a cylindrical mold chamber with nonconducting surfaces at both top and bottom. In this case, as in others where the chamber is of circular cross-section, the shrinkage cavity may be represented by a plane curve, since the cavity is symmetrical with respect to the ingot axis.

It is assumed that the mold chamber is instantaneously filled with liquid metal. Direction of solidi-

fication is radial and isothermal surfaces are cylindrical and coaxial with the mold chamber.

Case I.—Let

r = radius of mold chamber.

h = initial height of liquid in mold.

a = effective coefficient of contraction on passing from liquid to the solid state.

x and y = co-ordinates of surface of shrinkage cavity, x being measured from the longitudinal ingot axis and y vertically upward from the bottom mold plane.

In solidifying from the point x to the point $(x - dx)$ the total volume of contraction due to freezing is equal to $2axy.dx$. If the free surface of the liquid falls from a point y to a point $(y - dy)$ due to this contraction, then

$$\pi x^2.dy = 2\pi axy.dx,$$

$$\text{or } \frac{dy}{y} = 2a \frac{dx}{x}.$$

Upon integrating,

$$\log y = 2a \log x + C,$$

where C is the constant of integration. Now, $x = r$ when $y = h$. Hence, $C = \log h - 2a \log r$. Substituting this value of C in the above equation,

$$(6) \log y = 2a \log x + \log h - 2a \log r.$$

Case II.

In this case rate of solidification upward from the bottom of the mold chamber is at any instant assumed to be equal to that which is occurring radially from the wall. As in Case I, the top surface is non-conducting.

$$(7) \pi x^2.dy = 2\pi ax.dx(y - x) + ax^2.dx$$

Equation (7) is a differential equation homogeneous in x and y and can be readily put in proper form for integration by letting

$$y = ux$$

$$\text{and } \frac{dy}{dx} = u + x \frac{du}{dx}.$$

Substituting these values in equation (7),

$$u + x \frac{du}{dx} = 2au - a,$$

$$\text{or } \frac{du}{(2a - 1)u - a} = \frac{dx}{x}.$$

Integrating and replacing u by y/x ,

$$(8) \log x = \log r + \frac{1}{2a - 1} \cdot \log \left[\frac{y}{x} (2a - 1) - a \right] - \frac{1}{2a - 1} \cdot \log \left[\frac{h}{r} (2a - 1) - a \right]$$

the constant of integration being determined as before.

Case III.

The ordinary tapered mold chamber has a larger

cross-section at the bottom than at the top. The simplest case is that of circular cross-section, with nonconducting top and bottom surfaces.

Let

Θ = the angle subtended by the bottom ingot plane and a plane tangent to the curved surface of the mold chamber.

r_1 = radius of mold chamber at top.
 r_2 = radius of mold chamber at bottom.

The differential equation defining the shrinkage cavity is

$$\pi x^2 dy = \left[\frac{2 \pi x + 2 \pi (x + r_2 - r_1)}{2 \sin \Theta} \right] y a dx$$

Upon integration this yields

(9)

$$\log y = \log h + \frac{2a \log (x/r_1)}{\sin \Theta} - \frac{a(r_2 - r_1)}{2.3x} + \frac{ar_2}{2.3r_1} - \frac{a}{2.3}$$

Case IV.

In the case of the mold chamber of inverted taper where r_1 is greater than r_2 and Θ is greater than 90 degrees, the integrated equation (10) is identical with equation (9) except that the algebraic sign of the third term in the right-hand member,

$$\frac{a(r_2 - r_1)}{2.3x}$$

is plus instead of minus.

The Notable Difference Between the Pipe Obtained in an Ordinary Tapered Mold Chamber and in a Chamber of Inverted Taper

Inspection of the above differential equations shows that the surface of the shrinkage cavity becomes asymptotic to the longitudinal axis of the ingot with decreasing values of x when r_2 is greater than or equal to r_1 . However, when r_2 is less than r_1 (Case IV), the value of dy/dx becomes equal to zero when $x = 0$. In other words, the pipe surface is asymptotic to the ingot axis for the mold chamber without taper and for the ordinary tapered mold chamber, but cuts the axis at right angles at a certain distance above the base in the case of the inverted taper.

Fig. 1 shows the calculated shape and location of the pipe, in longitudinal axial cross-section, in a mold chamber 12 inches high for Cases I, III, and IV. Curve (1) is that of equation (6), Case I, where r is taken as 1.5 inches. Curve (3) is calculated from equation (8) for Case III, taking $r_1 = 2.75$ inches, and $r_2 = 3.25$ inches. Curve (4) is derived from equation (10), Case (IV), where $r_1 = 3.25$ and $r_2 = 2.75$. In each instance, a value of 0.02 has been assigned to the effective coefficient of contraction, a . It may be remarked that the curve for Case II was not plotted because it lies very close to that for Case I.

The calculated values of x and y from which these curves were constructed are given in Table I.

In the case of the mold chamber without taper (Cases I and II) the pipe extends the entire length of the ingot, although the radius of the pipe, or x , has decreased to 0.005 in. at a distance 9.5 inches above the basal plane. Likewise, in the ordinary tapered mold (Case III) the pipe extends the length of the ingot,

the effect of the taper being to enlarge the cross-section of the pipe along its lower extremity. In the case of the ingot of inverted taper (Case IV) the pipe ends abruptly at a distance of 11.24 inches above the base.

Effect Upon Pipe of Viscous Flow in the Liquid Steel

In the above calculations, the liquid steel has been assumed to flow like a perfect liquid. The existence of the property of viscosity in the liquid delays its down-

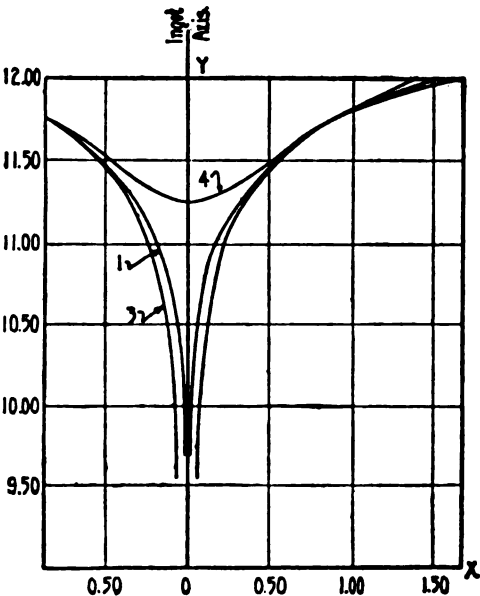


FIG. 1—Shape and location of pipe.

ward movement to a negligible degree at first, but, as the cross-section of the pipe section in contact with the liquid decreases in radius, viscous flow becomes an important factor and discontinuities in the lower part

TABLE I

	Case I	Case II	Case III	Case IV
x	y	y	y	y
1.625	.....	.....	.....	12.00
1.5	12.00	12.00	.....	11.96
1.375	11.96	.....	12.00	11.90
1.25	11.91	11.80	11.95	11.89
1.00	11.81	11.82	11.83	11.79
0.75	11.67	11.67	11.68	11.68
0.50	11.48	11.53	11.45	11.53
0.25	11.17	10.19	11.03	11.32
0.125	10.86	10.89	.....	.....
0.10	.....	.....	10.32	11.25
0.05	10.47	10.50	9.54	(pipe ends
0.01	9.82	9.84	6.00	at y = 11.24)
0.005	9.55	9.57	3.54	

of the pipe can appear, at least in the case of ingots which do not have an inverted taper.

Pipe Formation in Mold Chambers of Cross-Section Other Than Circular

Equations (6), (8), (9), and (10) were derived from a consideration of mold chambers of circular cross-section. They are the equations of the curves intersected on the surface of the shrinkage cavity by a vertical plane through the ingot axis.

(Concluded on page 136)

Seamless Steel Tubing; A Bibliography

Practically All Phases of Tube Manufacture Are Covered—Pilger
and Mannesmann Processes Receive Special Attention
—American and Foreign Practice Reviewed

Compiled by VICTOR S. POLANSKY*

(Continued from February)

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(To be continued)

Solidification of Steel in Ingot Mold

(Continued from page 132)

The same equations are applicable to any mold chamber of uniform or of uniformly tapered cross-section, provided there is substituted for x the expression $x \sec \Phi$, where Φ is the angle which the intersecting plane of reference through the axis makes with the wall of the mold chamber.

Effect of Rate of Pouring and Rate of Solidification Upon the Shrinkage Cavity

It has hitherto been assumed in the calculations relative to the shrinkage cavity that the mold chamber was initially full of liquid metal before solidification began. Actually, this is never realized in practice, since pouring consumes appreciable time. The mold wall receives a quantity of heat per unit area which increases from top to bottom, and solidification over a certain section of the wall proceeds, before the mold is filled with liquid.

Mathematical treatment of the case where pouring rate and rate of solidification are taken into account in deriving the equation of the shrinkage cavity is exceedingly involved and will not be attempted in the present paper. However, it is more or less obvious that the pouring rate factor is equivalent to a decrease in the cross-section of the ingot which is a maximum at the basal plane and decreases parabolically to zero at the top. This effect is, in other words, in the direction of the inverted taper, and it is conceivable that it may in certain instances be great enough to cause steel in a mold of ordinary taper to pipe in accordance with the law which is always an inherent characteristic of the inverted taper mold. Slow pouring and a high degree of superheat exert opposing influences, so that the advantage of the former may be completely neutralized by the latter.

Concluding Remark

The foregoing mathematical investigation of the solidification of steel in the mold is not offered with any idea that its methods can supplant the data and observations, obtainable by measurement or experience, but in the hope that it may stimulate further work along similar lines and eventually supplement the results of experimental measurement and plant practice to some advantage.

Economy Effected in Malleable Iron Plant

By the Installation of Equipment for Handling Sand and Conveyors for Carrying Molds Very Appreciable Savings Are Obtained—Labor Requirements Are Reduced

By R. J. HEISSERMAN*

THE American Radiator Company's new sand and mould handling system, at their Bond Plant, Buffalo, N. Y., has been in operation for over a year, and has had a good opportunity to prove its worth in efficiency and low maintenance cost.

The following table illustrates in a very impressive manner the comparison between the old floor method and the mechanical means whereby all the lifting, carrying out, shoveling and back breaking labor has been practically eliminated:

PRODUCTION OF MOLDS PER MAN HOUR —OLD METHOD

Small Davenport Unit	Snap Flask Unit	Maintenance Cost per 1000 lbs.
5.75	18.25	\$1.80

PRODUCTION OF MOLDS PER MAN HOUR —NEW METHOD

Small Davenport Unit	Snap Flask Unit	Maintenance Cost per 1000 lbs.
9.70	30.55	\$1.47

1—A 50 per cent saving in floor space is obtained by the mechanical method.

2—Mechanical methods require only 25 per cent of flask equipment formerly used under the old method.

3—Possibility of running two, or even three shifts a day in which case maintenance and investment costs are greatly reduced, is offered.

4—Night labor of shake-out sand preparing men entirely eliminated.

5—Storage of rough castings eliminated, as they proceed in a continuous flow to and through cleaning and machining departments.

The system, consists of one sand handling unit and two power mould conveyors.

The large mould conveyor runs in a horizontal plane, and travels in a rectangular path 68 ft. centre line in the long direction and 21 ft. 3½ in. across. The trays are made up of sections of gravity roll 21 in wide x 40 in. long, on the bottom of which are attached hard white iron wearing shoes which travel and slide on T-rail tracks.

The trays are propelled by a single strand rivetless chain, suspended from the bottom of trays by special long joint pins with cotters. In this way, while the chain is propelling the trays, the trays are supporting the chains and thereby eliminate any necessity for tracks, guides or rollers for the chain.

The conveyor is driven at one corner by a 10 hp. motor with a belt drive to a reducer. Two short sections of gravity conveyor run on each side of a set of moulding machines, on one of which the moulds are cored, closed and delivered to the power conveyor while the other is for returning the empty flasks to the moulding machines from the power conveyor.

After the mould is clamped it is pushed from the stationary gravity conveyor to the gravity roll trays

on the pouring conveyor. This arrangement, obviously, makes it unnecessary to lift the mould in transferring it to the power conveyor, and, as the transfer is made with the power conveyor in motion, no time is lost.

The moulds, having been placed on the power conveyor, travel toward the pouring end, and two men pour off as the moulds pass across the 21 ft. 3½ in. end. During the travel from the pouring zone to the shakeout end, the moulds are cooled, and just after they have turned the driving sprocket, they are manually pushed off onto a short section of gravity con-

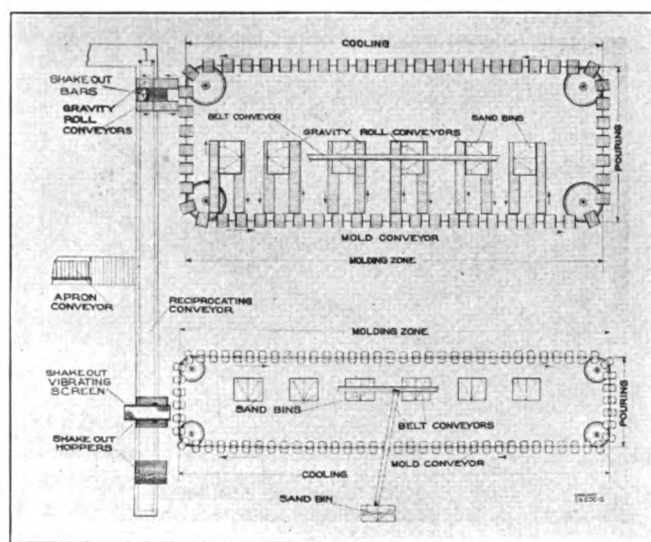


FIG. 1—Power conveyor for carrying molds.

veyor at one side of the shakeout grating. Here two men break the moulds and as they shake out the two halves they are placed on a second section of gravity conveyor by which they are returned to the power conveyor by a man at this point.

The castings are hooked out by a worker, when the cope has been removed, and there are several other workers here for removing castings to castings conveyor and for cleaning up.

Handling of Empty Flasks

The empty flask with bottom boards now travels back on the power conveyor to the moulding stations and as they pass the moulder who is using that particular flask they are pushed off of the power conveyor to the flask storage gravity conveyor alongside of each pair of moulders.

On the side of the foundry opposite to the conveyor described above, is the power mould conveyor for handling the moulds 12 in. wide x 16 in. long x 5 in to 8 in. deep, both of snap and steel flask variety. This conveyor is similar in construction to the other, with the following exceptions:

*Engineer, the Link-Belt Company.

The path of travel is 72 ft. long x 11 ft. 6 in. wide, the trays being hard white iron castings sliding direct on the T-rail tracks. The trays are spaced 27 in. apart and travel at a speed of 20 fpm. The corner sprockets are 57 in. pitch diameter and a $7\frac{1}{2}$ hp. motor furnishes the power. The actual horse power consumption is 4.2 hp.

Twelve moulders working on 12 squeeze type moulding machines place the completed moulds direct on the power conveyor. Just before the moulds turn the corner into the pouring zone, a man stationed at this point places a weight on top of them. Two men do the pouring as the moulds pass across the 11 ft. 6 in. side of conveyor, and, surprising as it may seem, they accomplish this work at the high speed the conveyor travels, without the aid of a moving pouring platform. The ladles used hold about 250 lbs. of iron, which is suspended from an overhead track with a chain block. About 5 seconds are required to pour each mould.

After the moulds have turned the next sprocket, or corner, and have started along the cooling side of the conveyor, weights are lifted off manually, and placed on a section of gravity conveyor which returns them to the weight placer on the opposite side of the power

a preliminary mixing and at the same time conveys it to the foot of elevator.

From the elevator the sand passes onto a 4 ft. x 5 ft. Link-Belt vibrating screen, driven by a 5 hp. motor, 2 hp. actually being consumed.

Located directly beneath the vibrating screen is a collecting hopper with a capacity of about 5 to 7 tons of sand, which is used to give a uniform feed of sand to the tempering belt. A gate is provided at the bottom of the tempering belt hopper so that the capacity can be regulated on the belt, and as the sand passes along it is raked, tempered and raked again before it is discharged into the revivifier.

Magnet Eliminates Iron in Sand

A magnetic separating belt has been installed over the tempering belt for drawing out small shot and particles of iron that have not been caught by the vibrating screen. The next machine in cycle of operation is the revivifier which is driven by a 15 hp. motor which also drives the tempering belt. The actual power consumption on this motor is 11.3 hp.

The sand being discharged from the bottom of the revivifier is collected on the foot end of the first distributing belt conveyor, (24 in. wide x 91 ft. centres) and is conveyed to plows which plow it off into the moulding sand hoppers over the Davenport moulding machines.

One man is used for tempering the sand at the tempering belt and a second one operates the plows on the first distributing belt feeding to the moulding sand hoppers. When these hoppers are all filled all the plows are raised and the sand is discharged over the end onto the cross belt conveyor which discharges onto the second distributing belt.

The second distributing belt, likewise, have a man in attendance for operating the plows; and when all of the bins are filled, sand passes over the discharge end and is either discharged back into the reciprocating conveyor or is used on some of the hand floors. The second distributing belt is 24 in. wide and has 73 in. centers.

Sand for the small gravity roll unit against the wall is also furnished from the second distributing belt by a 24 in. wide x 23 ft. center belt conveyor.

The two distributing and one cross belt conveyor are each equipped with a 5-hp. motor, and each consumes 3.5 hp. The short conveyor to the auxiliary moulding unit is equipped with a 3 hp. motor and readings show that it uses 2 hp.

Although there is very little sand storage in this system, there has been no difficulties experienced with hot sand, and a very fine finish is obtained on the castings without the use of facing. All of the moulding sand hoppers over the moulding machines are equipped with duplex gates, and are so located that the sand drops directly into the moulds.

Although the sand handling system was designed for handling 60 tons per hour, it is very often called upon to handle as much as 70 tons per hour.

This sand handling and preparing system is made up of the following Link-Belt machines: Shakeout hoppers, reciprocating conveyor, centrifugal discharge elevator, vibrating screen, collecting hopper under vibrating screen, tempering belt conveyor, magnetic separator, revivifier, first distributing belt conveyor, hoppers over Davenport machines, cross belt conveyor, second distributing belt conveyor, hoppers over snap flask moulding machines, auxiliary distributing conveyors, auxiliary mould hoppers.

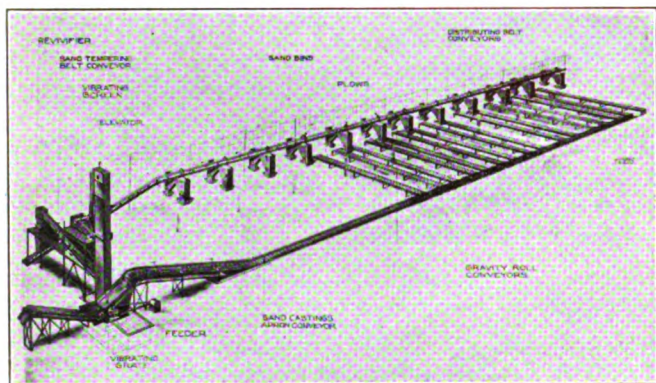


FIG. 2—Sand handling equipment.

conveyor. The moulds having traveled the full length of conveyor are cooled, and one man picks them up at the shakeout and dumps them into a vibrating shakeout screen, where the sand and castings are separated. The sand drops through to the shakeout grating, while the castings are discharged over the end into a wheelbarrow. Flasks, bottom boards and bands are again placed on the power conveyor trays and in this way are returned to the moulder, who picks off the ones he wants as they come to his station.

Between the small mould conveyor and the wall, is located a gravity conveyor moulding unit, consisting of a roll over and stripper and two lines of gravity roll conveyors. On one line of the gravity conveyor the moulds are cored, closed, poured, cooled and conveyed to the shakeout hopper. The second line of gravity conveyor is used for returning the empty flasks to the moulding machines and for storage of flasks. This unit is for large heavy work of a miscellaneous character that cannot be made on either one of the two power moulding units.

Sand drops through the gratings at the three shakeout hoppers and then is fed uniformly by feeders on the bottom of these hoppers to a 36 in. wide x 87 ft. long reciprocating conveyor. A 15 hp. motor drives this machine and power readings show that 13.4 hp. is consumed. The reciprocating conveyor gives the sand

Cutting and Welding at the Open Hearth*

The Use of the Oxy-acetylene Blow Pipe Facilitates Tapping,
Opening "Frozen" Nozzles and Reclaiming Scrap—Weld-
ing Equipment Makes Possible Emergency Repairs

AN open hearth furnace manufactures steel from pig iron, scrap iron and iron ore. Its bottom holds a pool of metal, perhaps 15 ft. wide, 30 ft. long and 18 to 24 in. deep, over which play flames of burning gas. Under this white heat the molten bath is gradually refined of its impurities, and then the steel is drawn off, separated from slag, and cast into ingots. Much more than half of the entire American output of steel is made in this way.

Since the ability of the open hearth process to re-make old material is one of the prime economic causes for its rapid expansion, the scrap yard is as vital a portion of the plant as the ore pile is of the blast furnace. This old metal comes from all directions; some of it is returned from the rolling mills as crop ends, or from forge and machine shops as trimmings and turnings. Heavy melting scrap, however, is cut by the oxygen lance and the oxy-acetylene blow-pipe. It comes from heavy machinery, ships, locomotives—all manner of massive metal sections which have outlived their usefulness.

It is unnecessary to present here a detailed discussion of the methods used in cutting up scrap. Huge shears are installed, capable of biting through large structural shapes. Heavy iron drop balls batter away at the more brittle castings. This equipment gets into trouble frequently, due to its excessively severe duties, and the oxy-acetylene process is available to build up worn shear tables, repair broken shear jaws of cast iron, rebuild broken gear teeth and worn cams. Even an 8-ton drop ball worth \$800, badly nicked and in imminent danger of going into the furnace itself, was trimmed back into useful shape in an hour's time.

Some pieces are much too big or tough for shearing or breaking. Heavy billets or ingots may be nicked (that is, cut part way through with the cutting blow-pipe), and then broken with the drop ball. Larger masses may be drilled with the oxygen lance and blasted, or if the location of nearby buildings prevent this, may be entirely cut apart. For instance, a 65-ton heat of steel, in the ladle, was carried to the end of the pouring aisle for what was thought to be a minor repair to the crane. It developed, however, into a far more serious matter, and since other cranes could not reach it the steel froze solid before the ladle could again be moved. Similar chunks in equally difficult locations have been successfully cut with the oxygen lance. Thousands of tons of such scrap, accumulated during war times, have also been reclaimed in this manner.

Charging Box Repairs

Charging boxes must withstand exceedingly severe service. Heavy pieces are dropped into them by a magnet. They are lifted by one end and knocked about none too gently by the charging machine.

Many steel plants cast their own boxes right on the pouring floor. Oxy-acetylene cutting is then used to remove the gates and risers. Others are made with

cast steel ends and plate sides. In a 20-furnace plant one welder can be kept busy continually making necessary repairs on battered and worn boxes.

The charging machine itself is probably the most essential part of a modern furnace plant. By it, a 60-ton furnace can be loaded in less than an hour; without it, furnaces of such capacity could not be operated, because they could not be filled by hand.

Despite this strenuous work, charging machines must be in first-class operating order when the furnace is ready for metal. Ordinarily the same crew of men who inspect and repair the overhead cranes look after the charging machines. Cutting and welding blow-pipes are their most useful tool. Trucks, trolleys, frames, drums, control equipment, shafting, gearing—a hundred different parts have from time to time been removed, rebuilt, or reclaimed with the oxy-acetylene flame.

The Furnace Itself

It is commonly said that the heart of the steel plant is the open hearth furnace proper.

Aside from the incidental cutting done during fabrication of the I-beams and other structural steel supports and furnace bracing, the oxy-acetylene process is indispensable for manufacturing the water-cooled doors and door frames. Many constructors also build water-cooled boxes into the brick work at various parts of the furnace, and about the gas and air ports, in order to prevent excessive scouring and to maintain the brick work in the proper lines. The oxy-acetylene flame also makes a joint which is far more successful in its ability to withstand the excessive temperature strains to which the piece is subjected than any other welding process.

Accidents to doors and door frames frequently occur; a plugged water pipe, or a heavy blow from the charging machine, may cause excessive warpage, buckling or cracking. It is notable that cracks seldom if ever occur at the oxy-acetylene welds themselves—almost always in the boiler plate. Doors and door frames are speedily replaced with spares; the dents are sledged out after heating locally with a large welding blow-pipe; cracks are also cleaned, veed and oxwelded at slight expense. Preheating at proper locations with welding blow-pipes will take care of the tendency of the repaired break to reopen, due to shrinkage strains.

Sometimes this water-cooled plate work is installed in vital parts of the furnace, and cannot be removed without dismantling the entire brickwork. Correct design, however, contemplates the occasional necessity to make repairs without a shut-down. Skew-back coolers, for instance, if leaking through the inner plates, have been repaired by cutting holes in the outer plates with the oxy-acetylene flame, repairing the break with a welding blow-pipe working through the hole, and then replacing the temporary door with the same hand-oxy-acetylene process.

A much more difficult repair was made in a cooler built into the bulkhead at the end of the hearth. It

*The Linde Air Products Company.

was surrounded with hot brick work, but by reaching through a convenient opening with a specially long water-jacketed blowpipe, the repair was made by an able operator standing yards away, behind a chain shield protecting him from the full furnace heat. What might easily have been a total shut-down and a major repair operation was thus converted into a temporary delay.

Special water-jacketed equipment is frequently made in the mills' own shops. At one plant in the Central States a change was made from natural gas fuel to by-product coke oven gas. It was then necessary to inject tar into the fuel, to produce a luminous flame. In this installation for handling tar, the oxy-acetylene flame was used extensively.

Openings through the brickwork at either end of the furnace were made and lined with a welded "dog house." Each was made in two halves which when assembled formed a conical, jacketed shell, having stayed surfaces and separate water inlets and outlets. It was 5 ft. in diameter at the rear end, 4 ft. at the inner end, and 4 ft. long, made by bending flat plate, oxwelding the joints, the staybolts and the water connections.

A quite complicated tar burner was thrust through this "dog house" injector. It had a central pipe for the tar, and a compressed air for atomizing the fuel. The tar pipe was steam jacketed to the end. Then a water jacket was placed as a sheath about the entire burner, to keep the surrounding heat from speedily melting it down. Such a fixture would ten years back be a poser to any shop, but was made very simply and readily of standard pipe, steel plate, and cutting and welding blow-pipes.

Furnace Tapping with Oxygen Lance

Since the chemical changes which transform the scrap, ore and pig iron into steel in an open hearth furnace are continuous reactions, it is necessary to remove the molten metal from the furnace promptly. The tap hole in most instances is opened by thrusting a long heavy bar through the peep-hole in the center door, across the furnace, down through the molten slag and metal. Several battering-ram thrusts by a crew of six or eight men will usually break through the bottom, and white-hot metal rushes through the spout into a waiting ladle.

If there is any delay here, if the plug sticks, if the half-sintered bottom caves into the hole, or if the charge breaks through of itself too soon, the metal must be held in the furnace a couple of hours longer to readjust its composition, or cast immediately to scrap. The first involves a loss of about \$100; the second, six or seven times as much.

These expensive (even if occasional) troubles are entirely avoided by one of the largest American steel companies by tapping each heat with an oxygen lance. (This, by the way, is merely a ½-in. steel pipe connected through a pressure regulator to an oxygen supply.)

The technique is simple:

One workman handles the lance; another is at the regulator adjusting the pressure. The lance end is put into the furnace for a few seconds until white-hot, and a few ounces of oxygen turned on. It will burn like a Fourth of July sparkler. It is then thrust into the tap hole from the outside, and the oxygen pressure at the regulator increased gradually, 5 lb. at a time, at the signal from the operator. He works the

lance in and out, and swabs the hole in all directions until it is of correct diameter. Usually, within a minute, and by the time the pressure has reached 40 lb., the hard dolomite plug has been pierced, and thin, reddish smoke shows that metal is being burned. Five seconds later the steel is flowing from the furnace.

On the average, it will require 40 cu. ft. of oxygen and 20 ft. of ¼-in iron pipe to do this work, costing approximately \$1.00 (less than the value of the 2-in. tapping bar, melted, twisted and reduced to scrap when opening the furnace by the other method.) Furthermore, it leaves the bottom of the tap hole in much better condition than when it has been battered open with a bar. In the latter case, it is frequently necessary to do more or less cutting with the lance after the heat is withdrawn, in order to smooth up the passage, and cut a good opening to the lowest part of the furnace.

Occasionally it is necessary to replace the steel runner, or spout leading from the tap hole. The lance or the cutting blow-pipe is indispensable to clean out the runner saddle and to remove the metal which clings to the outer wall of the furnace, just below the tap hole.

At the end of long campaigns, when the brick furnace lining has been badly melted, and the checker chambers (where the incoming gases are preheated) are clogged and slagged up, it is necessary to shut down completely and rebuild. Speed is required, in order to minimize the unproductive time of the unit. The cutting blow-pipe is very useful in the demolition—cutting away pipe connections of various sorts, loosening frozen tie rod nuts, slicing through warped and twisted buckstays. Sometimes a tough mixture of slag, brick and steel is found down deep in the bottom—this salamander must be cut small enough so that it can be removed by the moderately powerful cranes through the low headroom usually found in the furnace aisle. The hot, tough mass at the bottom of the slag pockets can also be easily drilled for blasting without waiting for it to cool.

Lance and cutting blow-pipe, working as a team, have removed spills which have accumulated under old furnaces for 25 years. At one plant several thousand tons of stratified steel, slag and dirt were removed after a visit of a service operator, and were reclaimed at a cost of \$4.50 per ton—less than half of its real value!

In rebuilding, the blow-pipe is always handy to aid in fitting and erecting the steel bindings, forms, railings, and water-cooled equipment. Much piping is being replaced with welded joints; the job is leak-proof, it eliminates a large stock of expensive fittings and unions, and it is done with common pipe more rapidly than the pipe fitter can cut out and thread the lengths.

Opening Frozen Nozzles

Aside from the frequent use of the cutting and heating blow-pipe in trimming and laying up plates when making a steel ladle, the oxygen lance is used at times during the actual teeming of the ingots. The nozzle in the bottom of the ladle is closed by a fire-clay stopper, attached to a bar and lever extending up over the ladle brim. By this arrangement the stopper can be raised or lowered at will, theoretically. If it refuses to open, or if only a thin trickle of steel shoots off at a crazy angle, the oxygen lance is brought

into play. With the end bent up square, so the operator can stand on the pouring platform well to one side, a stream of oxygen at about 25 lb. is directed into the nozzle. The hot steel obstruction obviously furnishes all the combustible material needed, so the lance can be protected by a hard wood sleeve slipped over the end. Only a second or two is required to bring a full flow of metal.

Ingot moulds are regularly cleaned before re-usage; but at times, due to shortage of equipment, careless pouring, or excessive boiling in the liquid steel, the accumulation of lacy splatterings around the top of the metal mould gets so thick as to interfere with the stripper. This spongy accumulation sticks like grim death, and can best be removed by slicing it through with the cutting blow-pipe at the corners and other appropriate locations, and then prying it loose with crowbars. No damage is done to the mold since it is a cast iron especially made to resist the scouring action of heat. The cutting blow-pipe is also needed frequently to free the coupling pins of ingot cars from frozen splatterings.

Special steels are ordinarily cast in "hot top ingots." By this means a pool of molten metal is maintained at the top to feed the shrinkage cavity forming below as the main mass of steel solidifies. These hot tops are frequently made of oxwelded steel plate, lined with fire clay. The whole construction must be especially rugged, to withstand the high temperature variations, and a crane man in a hurry, who will jerk the top loose by one handle. One design requires about 30 minutes of welder's time to make.

Slag Ladle Repairs

Slag ladles are more usually made of one big steel casting. Cracks sometimes develop in them long before their useful life is ended. These can be repaired with the oxy-acetylene blow-pipe, if proper attention to the preheating operation is given.

Gas Producers

A large share of the open hearth furnaces in this country are fired with producer gas, made from soft coal in a bank of producers housed immediately alongside the charging aisle.

Many repairs on parts, big and little, are constantly being made in the gas house. In one instance a steel gas producer top was repaired after a large crack had developed.

A water-cooled poker arm goes through the rectangular opening in the top. As the lower part of the producer rotates slowly, this arm is pulled back and forth by a crank shaft on the upper end. In this way the glowing mass of coal is constantly stirred, breaking up clinkers and closing chimneys. Some designers put removable ends on these arms, so the rapid corrosion from the hot contents will not scrap the entire arm. Rebuilding the worn tips with the manganese steel welding rod will increase the life of the tip to three months.

Work on Auxiliaries and on Building

Much hydraulic equipment is installed about an open hearth. Furnace doors are opened, gas and air valves are reversed, mixers are tipped, and cars are spotted by hydraulic power. Every time a control valve, cylinder, or ram is repaired by oxwelding, it is impressed on the workman that a similar joint would

save an enormous amount of trouble in the piping system.

Cutting and welding blow-pipes are always taken with the millwright gang when they start to do work about the open hearth building. Being entirely fire-proof and made of structural steel, it is most necessary for them to have this "hammer and saw for metal." Much of their work is done on exceptionally heavy or badly corroded metal. Cutting through laminated plate is frequently expedited by starting the cut from a hole pierced by an oxygen lance.

Large Precipitator for Trenton Channel

The first and only large installation of equipment for the electric precipitation of ash in a powdered fuel boiler plant is being installed at the Trenton Channel power plant of the Detroit Edison Company. The installation, having what will probably be the highest power rating of any single electric precipitation of plant ever built, is being made under the supervision of the Research Corporation of New York City, and involves the use of the Cottrell process.

The smoke given off from the Trenton Channel powdered fuel boiler plant carries with it a large amount of fine ash which, if it were not removed in some way, would result in the distribution from the stacks of many tons of ash over the surrounding countryside. By means of the new precipitator this will be practically eliminated.

Nine precipitator units will comprise the final installation, each being served by two 25-kv-a. electrical sets. Two precipitator units are already in use and the remainder will be installed early this year.

The high voltage power will be supplied from 18 specially designed, 25-kv-a. transformers, of which 14 units are now under construction at the Pittsfield plant of the General Electric Company. These units will step up the 220-volt, single-phase, 60-cycle power supply to 75,000 volts. The high voltage will then be passed through mechanical rectifiers built by the Research Corporation and each driven by a single horsepower, ball-bearing, synchronous motor of special design and furnished by the General Electric Company. The high voltage direct current from the rectifier will be applied directly to the treaters.

The precipitators are of the graded resistance type, consisting of parallel grounded concrete plates between which will be suspended anodes connected to the negative side of the d.c. circuit. The positive side of the d.c. circuit will be connected to the concrete plates and a corona discharge will flow from the suspended anodes to the concrete cathodes.

The smoke exhausted from the boiler plant will pass between the concrete plates and the suspended ash will be ionized by the corona discharge and deposited on the concrete plates whence it will be removed periodically by mechanical means, dropping into hoppers below. Periodic removal from the hoppers will complete the process.

By means of a number of taps in the low-voltage winding of each transformer, it will be possible to select the best operating voltage at which the precipitators will operate. These taps will provide, besides the 75,000 volts, voltages of 70,000, 65,000 and 55,000.

The POWER PLANT

*The Relation of Stokers to Boilers**

Early Attempts to Improve Combustion Heat Absorbing Surfaces
—Per Cent of Rating—Operating Difficulties—Selecting
Correct Boiler and Stoker for a Given Condition

By W. A. SHOUDY†

APPARATUS for the mechanical feeding of coal to a boiler furnace was developed primarily for the purpose of reducing human labor. Such appliances were called "mechanical" stokers to distinguish them from "human" stokers. The reduction of labor was not so great as expected until coal-conveying apparatus replaced the coal passer, but the mechanical stoker gradually gained popularity because, by the elimination of frequent opening of the fire doors, excess air was reduced and furnace efficiency increased. In common parlance, the boiler efficiency was improved, although the boiler had nothing to do with the improvement.

Early Attempts to Improve Combustion

By the use of forced draft, combustion rates of 40 lb. of coal per sq. ft. of grate surface could be obtained for short periods with hand-fired grates when the super-fireman could be found who could handle so large a quantity of coal. When the chimneys were high enough such combustion rates meant a horsepower output 25 to 30 per cent in excess of the boiler's rated capacity.

The rapid building-up of the fuel bed and the necessity for more frequent cleaning of fires limited such runs to a very few hours. The use of rocking or dumping grates helped the cleaning problem, but only slightly reduced the manual labor.

The application of forced draft to the chain-grate stoker and the development of the underfeed stoker and its operation with forced draft made continuous operation possible at these higher rates of combustion, because the extraordinary human effort was eliminated and cleaning of fires could be carried on without serious interruption to service.

The length of the grate was no longer limited by the distance that a man could throw coal with a shovel, hence stoker grates were soon extended beyond the length of the flat grate and a larger total weight of coal could be burned without increasing the rate of combustion per square foot of grate surface. More careful design of the stoker grate so as to get a more uniform distribution of coal in the fire bed and improvement in combustion-air distribution resulted in increased rates of combustion without sacrifice of furnace efficiency but rather, in most cases, an actual improvement. This increased liberation of Btu. per

sq. ft. of grate was delivered to the boiler heating surface and evaporated a larger quantity of water, and the era of high ratings began.

Since the heat-absorbing surface (the boiler surface) was not increased, higher rates of transmission were necessary and were obtained, but at the cost of increasing exit gas temperatures, i. e., at a reduction of heating surface efficiency. However, boiler tests showed in many cases an improved combined boiler and furnace efficiency. It should be obvious that this improvement was due to improved furnace efficiency.

Heat-Absorbing Surfaces

The increasing length of stokers rapidly pushed back the bridgwall until it became the rear wall of the boiler setting. The tubes were then lengthened to give a larger heat-absorbing surface, and the stoker was again lengthened to meet the longer tubes. With such combinations, operation at ratings of 300 per cent was not unusual. These high ratings were obtained at a sacrifice of combined efficiency, because of the higher exit gas temperature. Additional heat-absorbing surface was added as economizer or air-heater surface, which increased the combined efficiency without altering the combustion efficiency or boiler efficiency per se.

More boiler surface was next added by increasing the height of the boiler, thus reducing the work of the economizer or air heater, and in some cases eliminating them where the highest combined efficiency was not justified by the use factor or fuel cost.

For many years the preponderance of inclined straight-tube boilers were built with 14 tubes counted vertically. Additional surface was obtained by increasing the number of tubes vertically. This gave a cheaper boiler per sq. ft. of surface, but no larger stoker could be fitted under it than a 14-high boiler. Consequently no higher horsepower or steam output could be developed, nor could the stoker be operated at a higher rate of combustion or higher furnace efficiency. Because the heating surface was larger, the exit gas temperatures were lower; hence the combined efficiency of the higher boiler exceeded that for the 14-high boiler for the same steam output.

The 20-high boiler or its equivalent is quite common, and a few 24 tubes high have been in operation for a sufficient time to prove their worth. A boiler with 4-in., 20-ft. tubes and 18 tubes wide will have a heating surface, depending upon the number of tubes high, approximately as follows: 14-high, 6200 sq. ft.; 20-high, 8400 sq. ft.; and 24-high, 10,000 sq. ft.

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†Advisory Engineer, General Engineering & Management Corporation.

The same size of stoker will fit under each of these boilers because the floor space is the same. If, therefore, a stoker is selected for the first boiler which will permit of operation at 400 per cent of rating, 2480 hp. will be developed. If the first boiler is replaced by the 20-high and neither the coal nor the stoker is changed, no greater output can be obtained, and the maximum rating for this combination will be 295 per cent. If the 24-high is next substituted, only 248 per cent of rating can be obtained. Since the furnace conditions are the same in all three installations, the furnace efficiency will be the same for all, but the combined efficiency will be the highest with the 24-high installation. The heat liberated by the stoker is the same for all three, but the 24-high boiler presents a larger heat-absorbing surface and a lower exit gas temperature. If a larger stoker is installed with the larger boiler, it might be operated at 300 per cent of rating, developing 3000 hp.; however, that same stoker under a 14-high boiler would deliver the same horsepower, but the boiler would operate at 485 per cent of rating.

Per Cent of Rating

The term "per cent of rating," when applied to present-day boiler operation, is of little value and at times is even misleading unless the design of the boiler is specified. This is particularly true, for example, when comparison of the reports of the Hell Gate boilers and those of the new Interborough boilers is attempted. The last Hell Gate boiler is a 3-in. tube boiler whose surface approximates a 12-high, 4-in. tube boiler. The Interborough boiler is 24 tubes high. The ratio of heating to grate surface in the latter is therefore approximately double that of the former if the same stoker is used. The tests reported by Mr. Reynolds, showing 343 per cent of rating, represent a furnace condition approximating 686 per cent of rating on the Hell Gate boilers; whereas the highest reported rating on these boilers, 590 per cent (Power), is the equivalent of 295 per cent of rating on the Interborough boiler.

This comparison is not made for the purpose of drawing any conclusion as to the relative merits of the two installations, but merely to show of how little value are comparisons on the basis of per cent of rating. Intelligent comparison can be made between such widely separated installations by comparison of the stokers on the basis of pounds of coal or Btu. liberated per sq. ft. of grate area (actual or projected), and the boilers on the basis of evaporation per sq. ft. of heating surface or per foot front of boiler furnace. Until some one can develop an all-inclusive term, we must make our comparison on such a basis. The author hopes that the term "per cent of rating" may be eliminated from the steam engineer's vocabulary.

In stationary practice we have not reached the limit of evaporation for the steam boiler. This is shown by the higher ratios obtained in marine boilers. If the boiler feedwater is good and the boiler design such as to provide satisfactory circulation, there are apparently only minor operating difficulties experienced when operating boilers at high rates of evaporation.

It is nevertheless common to hear of interruptions to service due to operation at "high ratings." This is so much the case that "high ratings" have been left to the central station, and the industrial plant has generally kept to conservative operation. These ratings

have not always been as conservative as the purchaser has expected. Because of the fact that 14-high boilers have been successfully operated in industrial plants at 200 per cent of rating, 20-high boilers have been installed for the same rating, yet the latter furnace condition is the same as for a 14-high boiler at 275 per cent of rating. Unless the stoker and furnace are carefully selected for the high boiler, trouble may be expected; but not with the boiler.

Operating Difficulties

Operating difficulties at high ratings are due to one or more of the following causes:

- 1—Impure feedwater
- 2—Poor circulation, or insufficient steam liberating surface
- 3—Restricted feedwater supply
- 4—Grate or stoker trouble
- 5—Ash or clinker trouble
- 6—Refractory trouble

The first three can be foreseen and any one of them eliminated before it occurs, or the boiler installations must be limited to conservative rates of evaporation. The last three, or furnace troubles, cannot always be foreseen and are less easy to prevent. They all vary with the coal and are so interrelated that they cannot always be separated and studied. Perhaps the major difficulty is with the impurities in the coal.

Operating difficulties almost never occur at low combustion rates. The rate at which trouble begins is almost invariably determined by the impurities in the coal. Before the type of stoker can be selected the character of the coal must be known, as follows:

- 1—The relative ease of ignition.
- 2—The percentage of ash content
- 3—The fusion temperature of the ash

Each of these divisions may be subdivided still further, although this is generally unnecessary.

Anthracite is hard to ignite and its combustion is difficult to maintain. The finer sizes can best be burned in thin fires and when not agitated. The chain grate makes possible a thin fire without agitation as well as a continuous dump for the relatively larger ash content, and refractory arches for maintaining ignition can be installed without great difficulty.

Coke breeze offers generally the same difficulties, although some qualities have been burned successfully on under feed stokers; in general, however, both of these fuels are best adapted to the chain grate.

The eastern bituminous coals, with their higher volatile content and generally low ash, seem to have been created for the underfeed stoker. The fusing temperature of the ash is generally above 2400 deg. F., offering little clinkering trouble, and the highest combustion rates are easily obtained.

As we move westward into the fields of higher ash content and lower ash-fusion temperatures, the underfeed-stoker troubles begin. The continuous ash discharge or clinker grinder must be substituted for the dump plate because of the larger quantities of ash that must be removed, and a lower rate of combustion must be selected so that the fire bed temperature may not be sufficient to fuse the ash and cause clinker trouble. The chain grate is an active competitor in these territories because of its continuous

dumping action and the generally lower rate of combustion and thinner fire.

The sub-bituminous and lignite fields are still any one's territory, although pulverized coal at present seems to offer the best solution to this problem.

Another ash trouble is that due to the molten fly-ash which passes in to the boiler surface, adhering to the tubes and restricting the gas passages. This trouble varies with the coal and the rate of combustion. The lower rates of combustion apparently do not cause a sufficiently high gas velocity to carry the slag into the tube space. The front headers of some boilers have been raised 21 ft. above the boiler-room floor without completely remedying the trouble. Some improvement has been accomplished by leaving out alternate tubes in the lowest row or rows, thus eliminating bridging from tube to tube. Some of this fly-ash on reaching the colder space between the tubes is chilled and drops back into the furnace or passes through the boiler as hard ash. Preheated combustion air has helped in some cases and not in others. Some time must elapse before definite conclusions can be drawn as to this action.

For many years refractory failures were laid to too low a grade of firebrick or too high a furnace temperature, but it has become common knowledge that the chemical composition of the ash is just as large a factor in furnace design. Much of the erosion of the firebrick can be laid to the fluxing action of the molten ashes, especially those of low fusing temperature. Brick that will successfully perform with one coal will not do so with another because molten fly-ash washes away the brick until the wall fails or a state of equilibrium is reached when the heat radiated from the brick is sufficient to cool the surface to the congealing temperature of the ash. This trouble is more pronounced with pulverized coal than with stokers. The solution seems to lie in cooling the wall either by air or by water. The reduction in rate of combustion, that is, larger stokers or more of them, helps with some coals if the action is not severe.

Spalling is not always due to poor brick. Clinker adhering to the walls has a larger rate of contraction than the brick. On cooling the clinker shrinks and shears off the surface, leaving the brick with the appearance of having spalled.

Although these troubles are generally recognized, they have been mentioned because they emphasize the fact that furnace and stoker troubles are functions of the fuel quality and the rate of combustion. "High ratings" are therefore limited by these two factors.

Selecting the Correct Boiler and Stoker

The problem of selecting the correct boiler and stoker combination becomes one of selecting first the stoker and furnace and then selecting the best heat-absorbing surface that price of fuel, draft, use factor, and fixed charges will permit. The heat-absorbing surface will be the boiler alone or with economizer and air heater, or with either.

The size of the stoker will depend upon the quality of the coal and whether or not money can be spent for water- or air-cooled walls. It is doubtful whether water-cooled walls can be justified for boilers smaller than 750 hp., except possibly a patch at the base of the bridgwall or when the fluxing of the ash is unusually severe. Without water cooling, 60 lb. of coal per sq. ft. of projected grate area should be the maximum for underfeed stokers. With complete cooling,

75 lb. may be used; but in either case 35 to 50 lb. should be the rate for best operation. Preheated air may improve these rates, though complete data are lacking, and higher rates cannot be counted upon at present. We must content ourselves with the heat saving by the preheater and the better behavior of the fuel with preheat.

With anthracite 55 to 60 lb. should be considered a maximum, and the best rates taken as 30 to 45 lb. The higher rates will give capacity, but at the expense of loss of fine coal to the chimney.

It is impossible to completely catalog all fuels. Before selecting a stoker the behavior of the local coal should be observed on another installation, the correct rate of combustion selected, and the stoker proportioned accordingly.

For the purpose of illustrating the folly of selecting boilers solely on the basis of their respective performances at "per cent of rating," the author has included a brief study of boiler and stoker combinations for a plant to deliver 300,000 lb. of steam per hour from and at 212 deg. F. He has estimated the efficiencies of six different boiler and stoker combinations. In order that these efficiencies may be strictly comparable he has assumed one type of stoker, namely, the multiple-retort underfeed stoker, provided with rotary ash discharge or clinker grinder. He has assumed a coal of 14,000 Btu. dry basis with 7 per cent ash.

It is impossible to plot a curve of furnace efficiency, but the efficiency of the stoker can be indicated very clearly by the per cent of CO_2 and the per cent of carbon going out in the refuse. With low rates of combustion it is difficult to maintain low excess air, but at the higher rates a uniform per cent of excess air can be maintained with reasonably careful operation. The excess-air loss is therefore high at low rates of combustion. As the rate of combustion increases it becomes increasingly difficult to keep down the per cent of carbon going out with the ash. The efficiency of the stoker is therefore low at low rates of combustion, but reasonably flat over the intermediate rates. The assumed per cent of carbon in the refuse may be criticized as being too low. It does not represent past practice, but the author believes it represents what can be expected of a modern underfeed stoker.

Three types of boilers have been assumed, but all of them have the same furnace width and length. They are as follows:

- 1—620 hp., 14 tubes high
- 2—840 hp., 20 tubes high
- 3—1000 hp., 24 tubes high

All of these boilers are 18 tubes wide and the tubes are 20 ft. long. For the purpose of simplicity, as well as to obtain a more accurate comparison, all losses listed in the boiler heat balance are assumed constant at all outputs except the losses due to carbon in the refuse and chimney losses.

With the continuous dump or clinker grinder and rather complete water cooling of side walls, a maximum combustion rate of 75 lb. per sq. ft. of projected area may be expected. Under such conditions the 14-high boiler would deliver 640 per cent of rating; the 20-high, 540 per cent of rating; and the 24-high, 490 per cent of rating. With water-cooled walls we should not expect stoker troubles at these high rates because of the large size of stoker. We can, however, expect boiler troubles unless provision is made for a

high rate of feed to the boiler as well as abundant steam-liberating surface. Such boilers would also have to be operated with only the purest feedwater. Inasmuch as the assumed plant is of a relatively small size, it would hardly seem advisable to go to the expense of water cooling, in which case the rate of combustion might be kept to 60 lb. as a maximum with proportionately lower "per cent of rating." The per cent of rating mentioned above, of course, applies only to short periods. The continuous maximum rate should be limited to about 50 to 55 lb. per sq. ft.

Combined Efficiencies for Various Boiler and Stoker Combinations

Variations in plant loading throughout the year often require a larger number of boilers than the three mentioned above. The combined efficiencies have therefore been worked out for a plant with three, four, and five boilers, respectively. Inasmuch as stokers are made in standard sizes, it is impracticable to get a combination with which there will be exactly the same proportion of heating surface and grate surface. The proportion is indicated by the following statement:

Boilers	Stokers
3—1000 hp., 3000 hp. total	3—206 sq. ft., 618 sq. ft. total
4— 840 hp., 3360 hp. total	4—184 sq. ft., 736 sq. ft. total
5— 620 hp., 3100 hp. total	5—152 sq. ft., 760 sq. ft. total

The boilers are respectively 14 high, 20 high, and 24 high.

The reason for this condition is obvious when we note the total horsepower installed. Case 1 has the smallest total horsepower and the largest boilers; case 3 has the next largest horsepower, but the smallest boilers and the largest grate area; case 2 has the largest horsepower and the middle-size boilers; consequently, case 1 operates at the highest rating, case 3 at the intermediate rating, and case 2 at the lowest rating. The lower rating of case 2 offsets the lower exit temperature expected with the higher boiler, and case 3 has slightly lower efficiency, because the 14-high type of boiler has a higher exit temperature than the 20-high for the same rating.

A large number of other combinations might be worked out. If high overloads are not expected at this plant, slightly smaller stokers might be selected. Narrow, but longer, stokers might be installed in a five-boiler plant, using a higher boiler to get the same surface. This would work out a little more efficiently than the case selected. The exact answer cannot be worked out in such a way that it will apply to all boiler houses. The five-boiler combination would, of course, be the most expensive. There would be five settings to erect instead of three. The boilers and stokers would cost approximately the same, but the boiler house would be longer, greatly increasing the cost of the project. The determination of the number of units would be settled, not by a comparison of boiler efficiency, but by a comparison of the total cost of the project and by local conditions governing the number of boilers.

Basis of Selection

Enough data have been presented to show that the selection of the correct combination of stoker and boiler cannot be determined by rule-of-thumb methods, nor can it be based upon comparisons of opera-

tion at certain percentages of rating. The selection must be made in the following manner:

- 1—Determine the number of boilers that the variations in load and local conditions demand.
- 2—Select a grate surface of sufficient size to permit of conservative combustion rates.
- 3—Determine the rate of evaporation that feed-water conditions will permit.
- 4—Select the most efficient heating surface that draft, coal costs, and fixed charges will permit.

Steel Mill in Belgium Adopts Electric Drive

One of the largest steel mills in Europe is located near Liege in Belgium, and employs about 6,000 workmen. This is the Société Anonyme d'Ougrée-Marihay, a company which at the close of the war found its manufacturing plant completely stripped of machinery and was therefore faced with the necessity of buying and installing an entirely new equipment before taking up again the manufacture of steel.

Among the new machinery is a combined strip and wire rod mill. The main mill includes 14-in. and 12-in. roughing stands and 10-in. finishing stands. Wire rod up to 12 mm. diameter and strip up to 100 mm. width can be rolled.

The fresh start in equipping the works with new machinery gave a favorable opportunity for introducing the electric drive. Direct current motors designed for adjustable speed and rated respectively at 2,000, 1,200 and 1,000 hp. were connected to the three stands of the main mill. Besides the main rolls there are of course many requirements for auxiliary power in a steel plant, and the Belgian firm, Société d'Electricité & de Mécanique, was called upon to supply the auxiliary motors, of which a total of 34 were required, ranging in size from 9 hp. to 70 hp.

All of these motors are started and stopped by the means of switches placed where they are convenient for the workman, this being accomplished through a series of contactors and relays in the well known system of magnetic control. In addition to the 34 auxiliary motors there are nine others of the industrial type also subject to magnetic control. There are also two separately excited 15-hp. Type RC motors furnished for driving the vibrators for the strip apron conveyors, taking current from a 25-kw. Type RC generator belted to the main finishing train motor so that the speed of the vibrators when once adjusted bears a practically constant ratio to the speed of the finishing train.

The Société d'Electricité & de Mécanique is the representative in Belgium of the General Electric Company, U. S. A., and from the latter they obtained many of the parts that go to make up the motors and control equipment. The assembly was effected at their factory in Ghent where motor frames, starting resistors and control panels were constructed.

In general, current limit control was used. Twenty-six master switches and 18 push button switches were required for the auxiliary equipment and were assembled in seven control stations. The panels and resistors are mounted in closed galleries overlooking the mill. From the time that the initial adjustments were effected, the control equipment has been operating perfectly.

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Heat Transfer Through Insulation*

Concise, Well Presented Discourse on a Subject Not Well Understood—Terms Are Clearly Defined While Application of Formulas Is Explained by Examples

By L. B. McMILLAN†

THE fundamental theory of heat transfer in the steady state (uniform temperature conditions maintained at both warmer and cooler surfaces) has been well known throughout the past century by the leading authorities on heat transfer. Briefly, it is based on the same conception as Ohm's law: namely, that flow varies directly as the potential and inversely as the resistance.

The resistance to heat transfer is dependent upon the thickness, x , and conductivity, k . It varies directly as the thickness and inversely as the conductivity and is equal to x/k . Therefore, the simplest case of heat transfer through a material having flat surfaces is represented by the equation,

$$(1) \quad U = \frac{t_1 - t_2}{\frac{x}{k}}$$

in which U is the overall rate of heat transfer in Btu. per square foot per hour, t_1 is the temperature of the warmer surface and t_2 is the temperature of the cooler surface.

Thermal conductivity is defined as rate of heat transfer in one direction (in a direction perpendicular to an area) per unit area, per unit temperature differential per unit thickness, per unit time (Btu. per square foot, per degree temperature difference between surfaces per 1 in. thickness, per hour).

Conductivity is a specific property of a material. It is not dependent on the area, thickness or shape of the material. It is the same for a 0.1 in. thickness of the material as it is for a 10 in. thickness. It is the same for a uniform material whether the material is on a pipe or on a flat surface. It is a rate, not a quantity. The total quantity of heat transmitted is dependent upon the area, shape and length of path (thickness of material), but conductivity is not. Conductivity is dependent upon temperature, but this is also true of other specific properties of material, density for example. This relationship of conductivity and temperature will be discussed in detail later in this paper.

One Material and One Surface Resistance —Flat Surface

Often the temperature of the cooler surface is not known, the known temperatures being that of the warmer surface, t_1 , and that of the air surrounding the cooler surface, t_2 . Then the rate of heat transfer is given by the equation

$$(2) \quad U = \frac{t_1 - t_2}{\frac{x}{k} + \frac{1}{c}}$$

in which c is the rate of heat transfer from outer surface to air.

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The manner in which rate of heat transfer varies as the thickness of the insulation is increased is illustrated in Fig. 1. It will be noted that the transfer through 2-in. thick material is somewhat greater than half of that through 1-in. thick material. The reason for this is clearly apparent in equation (2). Doubling the thickness doubles the value of the term x/k , but does not double the value of the term $1/c$. Consequently, since the value of the denominator in the case of 2 in. thickness is somewhat less than double the value for 1 in. thick, the value of U for 2-in. thick material must be somewhat more than one-half of its value for 1-in. thick material.

The term x/k represents the resistance of the material in question and the term $1/c$ represents the surface resistance. The lack of thorough understanding of the surface resistance is perhaps responsible for more confusion in the literature of heat transfer than any other single item. The failure to separate the effects of surface resistance from those of insulation resistance is the cause of most of the conflicting conceptions of conductivity.

In some cases surface resistance is the controlling factor in total rate of heat transmission. For example, in the case of a $\frac{1}{4}$ in. thickness of a metal having a conductivity of 2500 Btu. per square foot, per degree temperature difference between surfaces per 1 in. thickness, per hour, and with a temperature difference of 1 deg. F. between surfaces, the rate of heat transfer per square foot, per hour would be

$$\frac{1}{\frac{0.25}{2500}} = 10,000 \text{ Btu.}$$

If, however, the temperature difference between the warmer surface and still air surrounding the cooler surface is 1 deg. F., and the rate of heat transfer from surface to air is 2.0 Btu. per square foot per deg. temperature difference per hour, the total heat transfer per square foot per hour would be

$$\frac{1}{\frac{0.25}{2500} + \frac{1}{2}} = \frac{1}{0.0001 + 0.5} = 1.9996 \text{ Btu.}$$

(or for all practical purposes = 2.0 Btu.)

In this case the surface resistance is 99.98 per cent of the total and the resistance of the metal is practically negligible. In such a case a variation of 100 per cent in the conductivity item would have no appreciable effect on the total.

On the other hand, in the case of well insulated surfaces, surface resistance is a very small part of the total. For example, in the case of a 10 in. thickness of a material having a conductivity 0.25 Btu. per sq. ft., per deg. temperature difference per 1 in. thickness, per hour, and with a temperature difference of 1 deg.

F. between surfaces, the rate of heat transfer would be

$$\frac{1}{\frac{10}{0.25}} = 0.025 \text{ Btu. per sq. ft. per hour.}$$

If the temperature difference between the warmer surface and still air surrounding the cooler surface is 1 deg. F., and the rate of heat transfer from surface to air is 2.0 Btu. per sq. ft. per deg. temperature difference per hour, the rate of heat transfer would be

$$\frac{1}{\frac{10}{0.25} + \frac{1}{2}} = \frac{1}{40 + 0.5} = 0.0247 \text{ Btu.}$$

per sq. ft. per hour.

In this case the surface resistance is only 1.25 per cent of the total.

In the first example, neglecting to take account of surface resistance would make the result 5000 times too large. In the second example, the surface resistance influences the result only to the extent of about $1\frac{1}{4}$ per cent. These are representative of the two extremes, but actual cases will be found in practice over this entire range and at times even more extreme cases will be encountered.

This illustrates the importance of surface resistance. The matter would be greatly simplified if surface resistance were a relatively constant quantity, but it is not. It is influenced by the temperature of the surface, the temperature of surrounding objects, the nature of the surface, the position of the surface, the velocity of air currents over the surface, and by many other causes. Fortunately for the solution of insulation problems the value of surface resistance is usually small as compared with the insulation resistance—usually less than 25 per cent, and frequently less than 10 per cent of the insulation resistance. Therefore, with even approximate data on surface resistances such problems may be solved with a very satisfactory degree of accuracy.

One Material, Two Surface Resistances, Flat Surface.

When the temperature of neither the inner nor outer surface is known, and the known temperatures are those of the air on either side of the insulation, the equation for heat transfer is

$$(3) \quad U = \frac{t_o - t_a}{\frac{1}{c_1} + \frac{x}{k} + \frac{1}{c_2}}$$

in which t_o is the temperature of the air on the warmer side, c_1 is the rate of heat transfer from air to surface on the warmer side and c_2 is the rate of heat transfer from cooler surface to surrounding air.

The inside surface resistance $1/c_1$, is not used when the temperature of the warmer surface is known. Also, its magnitude is often negligible where effective insulation is placed directly against a heated surface the temperature of which is known. However, it is included in these general equations in order that it be not neglected in cases where it should be taken into account.

Except on flat surfaces the internal resistance of a material does not vary directly as the thickness. In

the case of cylindrical surfaces, increasing the thickness supplies additional resistance through which the heat must flow, but at the same time increase the area of the path through which the heat may flow.

One Material, Cylindrical Surfaces

The rate of heat transfer per hour, per sq. ft. of outer surface, through a single layer of uniform mate-

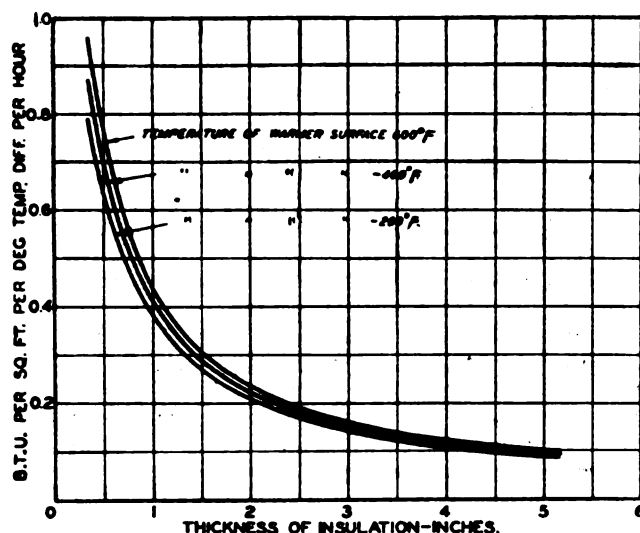


FIG. 1—Variation of heat transfer.

rial on a cylindrical surface, when the temperatures of the two surfaces are known, is given by the equation

$$(4) \quad U_2 = \frac{t_1 - t_2}{\frac{r_2 \log_e \frac{r_2}{r_1}}{k}}$$

in which t_1 and t_2 are the temperatures of the warmer and cooler surfaces respectively, r_1 is the external radius of the pipe or cylinder and r_2 is the radius of the outer surface of the insulation.

The loss per square foot of pipe surface is

$$(4a) \quad U_1 = \frac{r_2}{r_1} \times U_2$$

in which U_1 and U_2 represent the rates of heat transfer per hour per square foot of pipe surface and outer surface of insulation respectively.

Equation (4) might have been written to give transfer per square foot of pipe surface directly by substituting $r_1 \log_e r_2/r_1$ where $r_2 \log_e r_2/r_1$ appears. However, the reason for giving preference to the form of equation which results in loss per square foot of outer surface will be apparent in connection with subsequent equations involving surface resistance. The surface resistance most frequently applies to that surface, therefore it is more convenient to calculate the rate of transfer per square foot of outer surface. Then the loss per square foot of pipe surface is easily calculated from U_2 by means of Equation (4a).

It will be noted that the expression $r_2 \log_e r_2/r_1$ occupies the same position in Equation (4) that the thickness, x , occupies in Equation (1). In fact, this expression is frequently referred to, for convenience, as "equivalent thickness." It is numerically equal to the thickness of material on a flat surface which would

be required to give the same rate of heat transfer as that per square foot of outer surface of insulation on the cylinder or pipe.

Conductivity—A Function of Temperature

Conductivity has already been defined at the outset of this paper, and was there shown to be a specific property, not dependent upon the area, shape or thickness of the material. It has long been recognized that the conductivities of insulating materials are higher at the higher temperatures. It is reasonable that this should be so; because, due to the porosity of their structure, heat is transferred within these small spaces by radiation, convection and conduction, in addition to that conducted by the solid particles in actual contact, and both radiation and convection increase more rapidly than the first power of the temperature.

It is well known that insulating materials owe their insulating value to the porosity referred to above, and often it is said that the air spaces are responsible for the low conductivity. That is true as far as it goes, but a more complete statement of the situation would be that it is the multitude of surface resistances at the boundaries of the air spaces which give the material its resistance to heat flow. Because of the close proximity of the warmer and cooler walls of these spaces, the magnitude of each of these surface resistances is naturally small as compared with the resistance at an outer surface, yet because of their multitudinous number the sum of all of these small resistances may result in a total resistance of relatively high magnitude. The solid material between the spaces may be relatively a good conductor of heat, yet if the physical structure of the particles be such as to provide a sufficient number of spaces with their corresponding surface resistances, the resulting product may be a very good insulation. This is illustrated by the fact that the conductivity of magnesium carbonate in the form in which it is used as an insulation is about one thirtieth of that of the same material in solid form. An even more striking example is the case of carbon which in the form of graphite has a conductivity more than 200 times that of carbon in the form of lampblack.

The effect of temperature on conductivity has been taken into account by different investigators in various ways. The four most common methods of expressing conductivity are as follows:

- (a) As a function of temperature difference between surfaces.
- (b) As a function of the temperature of the warmer surface.
- (c) As a function of temperature difference between warmer surface and room temperature.
- (d) As a function of mean temperature.

Since conductivity is a function of temperature and not of temperature difference, method (a) is subject to serious errors. The conductivity of a material within one surface at 100 deg. F., and the other at 200 deg. F., will be much lower than the conductivity of the same material with one surface at 500 deg. F. and the other at 400 deg. F. even though the temperature difference in each case is the same.

Since conductivity is a function of temperature, the correct basis of expressing its value is in terms of conductivity at the mean temperature of the material, ((method d). This mean temperature is the arithmetical mean of the temperatures of the two surfaces and is not the temperature at the physical center of the material.

Carl Hering¹, and L. L. Barrett², have shown that where the curve of conductivity with respect to temperature was a straight line, the average conductivity for the entire thickness of material under consideration was equal to the true conductivity at the arithmetical mean of the two surface temperatures. The author has shown³ that this relationship applies with a satisfactory degree of accuracy to conductivity curves of considerable curvature, as well as to straight lines. The average conductivity is equal to the true conductivity at the temperature

$$(5) \quad t = \sqrt[n+1]{\frac{T_1^{n+1} - T_2^{n+1}}{T_1 - T_2}}$$

but the arithmetical mean of the surface temperatures closely approximates the value of this expression for a considerable range of values of n .

Conductivities expressed in this way may be used in computations involving a given layer of material regardless of whether it is used alone or in combination with other layers of material. All that is necessary is that the mean temperature of the layer of material be known. In the past it has usually been necessary to arrive at this mean temperature by the "cut and try" method which was quite tedious. However, in his own work the author has used for several years past a method whereby the mean temperature of each layer of material in combinations of two materials may be determined graphically with a highly satisfactory degree of accuracy. This method makes the computations for combinations of two materials extremely simple and may be extended to minimize the "cut and try" required for any number of materials. However, usually there are not more than two materials of major insulating value in a given construction.

Surface Effects

It has already been pointed out that the investigation of surface resistance offers a most fruitful field for further research. This does not mean that information on the subject is wholly lacking. In fact, sufficient data are available for the solution of most insulation problems with a highly satisfactory degree of accuracy. However, the deficiency of the work in this field (and the author makes no exception of his own earlier published results in this connection) is that results presented are over-all coefficients and make no provision for the separate effects of radiation and convection. One of these effects, radiation, is a function of the difference of the fourth powers of the absolute temperatures, while the other, convection, is generally considered to be a function of temperature difference. Therefore, while the results may be applied with assurance of accuracy to conditions closely approximating those under which they were obtained, they may not be extended very far beyond the range of actual experimentation.

Effect of Air Velocity on Heat Transfer from Surface to Air

The principal need for more complete data on surface losses is that, until these are accurately expressed in terms of their component parts, radiation and convection, and until the effect of air velocity on the latter has been accurately determined, no satisfactory state-

¹Trans. American Electrochemical Society, vol. XXI, page 520.

²Trans. A. S. M. E., vol. 44, page 315.

³Journal A. S. M. E., October 1924, page 603.

ment of the effect of air velocity on heat losses from surfaces may be obtained. The work of Langmuir is outstanding in this connection.

For radiation he uses the Stefan-Boltzmann equation, which, in engineering units may be expressed as

$$(6) \quad W_R = 0.178 E \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right]$$

and for convection he has developed the equation, which for still air under average conditions may be expressed as

$$(7) \quad W_C = 0.296 (T_1 - T_2)^{1/4}$$

The total rate of heat transfer is represented by the sum of these. He shows that convection is increased by air circulation, according to the equation

$$(8) \quad W_{cv} = W_c \sqrt{\frac{V + 68.9}{68.9}}$$

The increase in heat transfer due to air velocity calculated from these equations, at various surface temperatures and with an air temperature of 80 deg. F. are shown in Fig. 2.

In the above equations, W_R and W_C represent respectively the rates of heat transfer by radiation and by convection under still air conditions. W_{cv} represents rate of heat transfer by convection at any air velocity. All are expressed in Btu. per square foot per hour. E is the emissivity coefficient which for black body conditions is unity. T_1 and T_a represent the absolute temperatures of hot surface and of air, respectively, and T_2 represents the absolute temperature of surrounding objects to which heat is radiating. V represents the velocity of air flowing over the surface, expressed in feet per minute.

Effect of Air Velocity on Heat Transfer Through Insulation

In the case of well insulated surfaces the increases in heat losses due to air velocity are very small as compared to the increases just shown for bare surfaces. This is due to the fact that air flowing over the surface of the insulation can increase only the rate of heat transfer from surface to air and cannot change the internal resistance to heat flow inherent in the insulation itself.

The effect of the air circulation, therefore, is to cool the surface of the insulation to a temperature lower than it would have under still air conditions, thereby increasing the temperature drop through the insulation. Since the heat transfer in a given case is proportional to the temperature gradient, it is obvious that the heat flow will be greater when the temperature difference is $t_1 - t_2$ than when it is $t_1 - t_2$.

In the case of surfaces located out of doors, the combined effect of wind and rain may bring the surface temperature of the insulation practically down to the air temperature, yet even in this extreme case the increase in heat loss through the insulation is not as great as might be expected. This is illustrated by the following example, based on a flat surface insulated with 2-in. thick material, having a conductivity of 0.5 Btu. per square foot, per degree temperature difference per 1 in. thick, per hour and a rate of heat transfer from its surface to air under still air conditions of 1.8

Btu. per square foot per degree temperature difference per hour.

$$\text{Internal resistance of insulation} = \frac{2}{0.5} = 4.0$$

$$\text{Surface resistance} = \frac{1}{1.8} = 0.556$$

$$\text{Total resistance} = 4.556$$

$$\text{Rate of heat transfer} = \frac{1}{4.556} = 0.22$$

If the surface resistance were completely eliminated, due to the cooling action of wind and rain, the

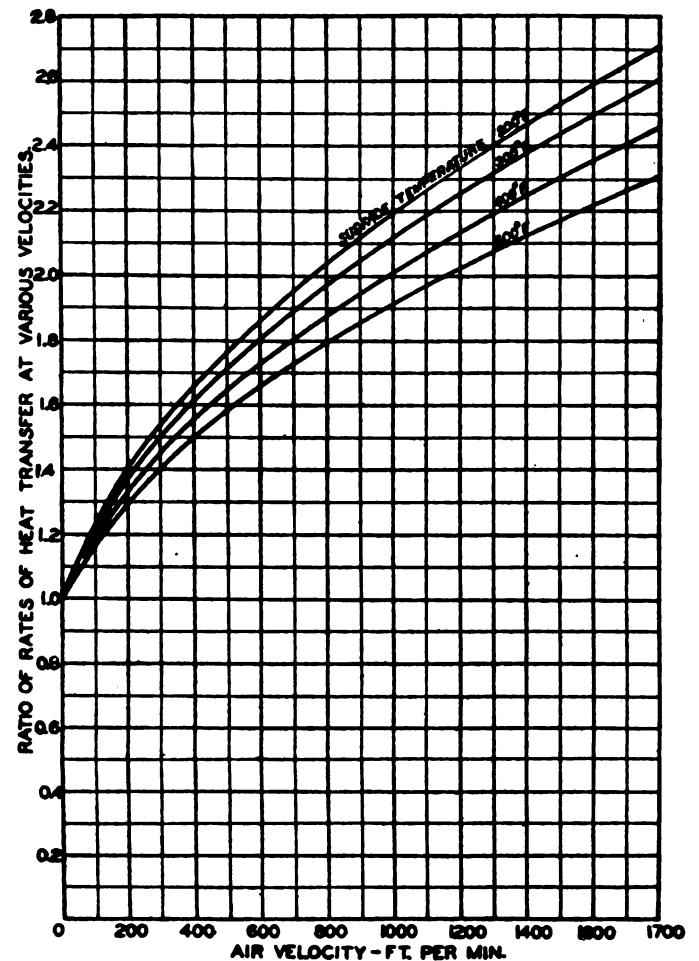


FIG. 2—Increase in heat transfer.

internal resistance of 4.0 would still remain, and the rate of heat transfer would be $1/4.0 = 0.25$ Btu. per square foot per degree temperature difference per hour. Therefore, the maximum increase in loss due to wind and rain would be

$$\frac{0.25 - 0.22}{0.22} = 13.6 \text{ per cent.}$$

In like manner, it may be shown that the maximum increase for 1 in. thickness of the same material under the same conditions is 27.9 per cent and, in the case of 3 in. thickness, 9.2 per cent. It is therefore apparent that the thicker or the more efficient an insulation is, the less its rate of heat transfer will be affected by air circulation.

Surface Temperature no Satisfactory Measure of Heat Transfer

The lack of a simple means to measure approximately the amount of heat loss from surfaces has naturally led to a widespread feeling that the degree of effectiveness of insulation may be estimated by the surface temperature. Probably no other conception in connection with heat transfer is so generally misused as this one. Surface temperature considered alone, without reference to temperature of surroundings, is absolutely no measure of the rate of heat transfer. A surface at 150 deg. F. in a confined space ex-

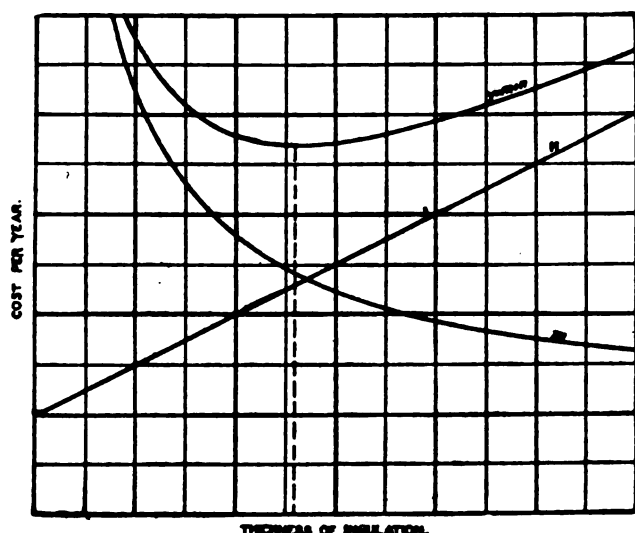


FIG. 3—Insulation as it affects costs.

posed to air at 150 deg. F. may be losing no heat at all, whereas a surface at 100 deg. F. exposed to air at a temperature of 50 deg. F. is losing heat in very considerable quantities.

Measuring the difference between the surface temperature and the air temperature is a little better, but not much, unless all other conditions are identical—which they rarely are. It is easily possible for the losses to vary over a range of several hundred per cent at the same temperature difference, depending on the air velocity to which the surface may be exposed. Nor is it necessary for that velocity to be very high in order to render either surface temperature or temperature difference, surface to air, entirely valueless as an indication of heat loss.

Economic Data

Perhaps the most valuable use for accurate data on heat transfer in connection with insulation is in the cal-

culation of the thickness of insulation required under various conditions for most economical results. There have been many contributions to the literature on this subject, but most of the methods presented have been graphical. A notable exception is P. Nichols' contribution on the "Economic Thickness of Insulation in the Refrigerating Field." However, long before that paper was presented, the author had been using in his own work a rational analytical method for insulation on flat surfaces and has just recently extended this to apply to pipe surfaces.

Referring to Fig. 3, as the thickness of insulation is increased the cost of heat lost per year (m) is decreased, but the cost per year of insulation (n, first cost multiplied by per cent fixed charges) is increased. Therefore, the thickness at which the sum of these two costs is a minimum is obviously the most economical.

For flat surfaces this may be determined from the equation

$$(9) \quad x = \sqrt{\frac{ak}{b}} - Rk$$

in which x is the most economical thickness, k is the conductivity, b is the cost of insulation per inch thick per year, R is the sum of the resistances of all other elements in the construction, including surface resistance, and

$$(10) \quad a = \frac{Y(t_o - t_a)M}{1,000,000}$$

in which Y is hours operation per year, t_o is inside temperature, t_a is temperature of surrounding air and M is the value of heat in dollars per 1,000,000 Btu. In Table I are given values of (a) for various temperature differences and various values of heat.

Equation (9) applies to combinations of any number of materials, the resistance of all but one being provided for in the term (R). The physical explanation of the situation is that the value of the term

$$\sqrt{\frac{ak}{b}}$$

gives the thickness of the one material which would be required if there were no other insulating value in the construction than that offered by the material itself. If only one material is involved, the only deduction required is that for surface resistance. The term R_k is then the thickness of material with conductivity (k) which has the same resistance as the surface resistance. In like manner deductions are made for the

TABLE I—VALUES OF "a"

Temp. Diff. Deg. F.	Value of Heat in Dollars per Million Available Btu.									
	.10	.20	.30	.40	.50	.60	.70	.80	.90	1.00
100.....	.088	.175	.263	.350	.438	.526	.613	.701	.788	.876
200.....	.175	.350	.526	.701	.876	1.051	1.226	1.402	1.577	1.752
300.....	.263	.526	.788	1.051	1.314	1.577	1.840	2.102	2.365	2.628
400.....	.350	.701	1.051	1.402	1.752	2.102	2.453	2.803	3.154	3.504
500.....	.438	.876	1.314	1.752	2.190	2.628	3.066	3.504	3.942	4.380
600.....	.526	1.051	1.577	2.102	2.628	3.154	3.679	4.205	4.730	5.256
700.....	.613	1.226	1.840	2.453	3.066	3.679	4.292	4.906	5.519	6.132
800.....	.701	1.402	2.102	2.803	3.504	4.205	4.906	5.606	6.307	7.008
900.....	.788	1.577	2.365	3.154	3.942	4.730	5.519	6.307	7.096	7.884
1000.....	.876	1.752	2.628	3.504	4.380	5.256	6.132	7.008	7.884	8.760

insulating values of other elements already present in the construction. If it is desired to increase the thickness of the first layer for some reason, as for example to reduce the temperature to which the second layer is subjected, the solution is very simple. The value of the term

$$\sqrt{\frac{ak}{b}}$$

does not change, but the value of R is increased and the thickness of the outer layer correspondingly decreased.

In the case of pipe surfaces, the equation for economical thickness is not quite so simple, yet it is by no means as formidable as it appears at first sight. For one material the cost of which may be expressed by the equation,

Cost per linear foot

$$(11) \quad = \frac{2\pi r_2 b}{12} (r_2 - r_1) + C$$

$$(12) \quad (r_2 \log_e \frac{r_2}{r_1} + R_s k) \cdot \sqrt{\frac{2r_2 - r_1}{r_2 - R_s k}} = \sqrt{\frac{ak}{b}}$$

All terms in these equations have previously been defined.

Conclusions

It has been shown that the phase of heat transfer in which further research is most urgently needed is in the whole broad field of surface effects. In this connection it is not amiss to suggest that where the pure scientist misses the mark is that he probably feels an entirely justifiable satisfaction in being able to set up an equation which provides adequately for the effect of every variable, and the more complex the equation the more keen the satisfaction, but he fails to extend his analysis a step further to the point which makes the application of the equation to actual cases conveniently useful.

If this paper makes any considerable headway in clarifying the meaning and use of the term conductivity, and in emphasizing the importance of a thorough understanding of surface resistance it will have been worth the effort and more. To those who have made a lifetime study of heat transfer, the treatment of the subject in this paper will appear for the most part elementary in the extreme. The presentation is elementary, and that it is such is intentional. The literature of heat transfer is expanding rapidly and it is essential that, if the current literature is to add anything of material value to the fund of knowledge on the subject, it must be based on the sound foundation of fundamental principles. It is useless to attack the more difficult problems without a clear understanding of these basic principles.

Definition of Symbols

- x = thickness of insulation
- k = conductivity—(Btu. per sq. ft. per degree temperature difference between surfaces per 1 in. thick per hour)
- S = shape factor
- t_o = temperature of air on warmer side of insulation
- t_1 = temperature of warmer surface of insulation
- t_2 = temperature of cooler surface of first material
- t_a = temperature of air on cooler side of insulation

c = rate of heat transfer from air to surface or from surface to air

c_1 = rate of heat transfer from air to surface

c_2 = rate of heat transfer from surface to air

R = resistance

R_s = surface resistance

r_1 = inner radius of insulation

r_2 = outer radius of first material

r_x = outer radius of any layer of material

U = over-all rate of heat transfer per hour

U_1 = over-all rate of heat transfer per sq. ft. of pipe surface per hour

U_2 = over-all rate of heat transfer per sq. ft. of surface at radius per hour

W_R = rate of heat transfer from surface by radiation Btu. per sq. ft. per hour

W_C = rate of heat transfer from surface by convection, Btu. per sq. ft. per hour

W_{CV} = rate of heat transfer from surface by convection, Btu. per sq. ft. at any velocity

T_1 = absolute temperature of hot surface

T_2 = absolute temperature of surrounding objects

T_a = absolute temperature of air

E = emissivity

V = air velocity, feet per minute

Y = hours of operation per year

$a = \frac{Y(t_o - t_a)M}{1,000,000}$

b = cost of insulation per sq. ft. per 1 in. thick per year

M = value of heat in dollars per 1,000,000 available Btu.

International Combustion Engineering Corp. Acquires Heine Boiler Company

International Combustion Engineering Corporation has officially announced the acquisition of the capital stock of the Heine Boiler Company, one of the oldest and leading water-tube boiler manufacturers in the United States. This acquisition gives the International Combustion Engineering Corporation large boiler shop facilities at St. Louis, Mo., and Phoenixville, Pa.

All types of water-tube boilers will be manufactured at St. Louis, including the new Sinuous Header type recently placed on the market. The manufacture of the Ladd water-tube boilers and the new Combustion steam generators will also be centered in the St. Louis plant.

The acquisition of the Heine Company will enable the International Combustion Engineering Corporation to furnish to its customers complete steam generating units fired with pulverized fuel or mechanical stokers, all of its own manufacture.

It is understood this new acquisition requires no financing by International Combustion Engineering Corporation, the Heine Company having been acquired through a cash payment. Mr. C. R. D. Meier will remain as president of the Heine Boiler Company.

Correction

The all cooling copper used in the construction of Weirton Steel Company No. 2 blast furnace was furnished by the Lawrenceville Bronze Company.

In the descriptive article covering this furnace which appeared in the January issue, this item was credited to the Falcon Bronze Company.

Gas Scrubbing in the Steel Industry*

Characteristics of the Various Gases and the Removable Constituents Are Described—Methods of Eliminating Objectionable Particles Discussed

By W. J. MCGURTY

THE several gases used in this industry for both fuel and power requirements contain quantities of both solid and vapor constituents, the amount and character of which are dependent on the source and the conditions under which they have been generated.

Apparatus and processes have been devised for the removal of the marketable impurities—so called by-products—although in every one of the artificial gases there are still constituents the removal of which would enhance their utilization value.

Classified as to thermal values, we have natural gas, coke-oven gas, bituminous producer gas, and blast-furnace gas, comprising the group usually associated with iron and steel plant operation.

Natural Gas

The natural gas of the Pennsylvania and West Virginia fields carries from 0.2 to 0.5 gallon per 1000 cu. ft. of the paraffin hydrocarbons found in gasoline. The recovery of the gasoline content is usually effected by absorption in mineral seal oil, and in various types of absorbers, horizontal, vertical and mechanical.

Those of the vertical type (towers) are packed with various materials and some combine bubbling and scrubbing action in the same shell.

With the advent of the mechanical absorber in this service, it has been possible to operate with reduced volumes of absorbent oil, at the same time securing a greater yield of the higher tension hydrocarbons such as butane, which when compressed makes a good cutting gas owing to its high thermal values, 3,274 Btu. per cu. ft.

The gradual depletion of natural gas has been responsible for the rapid development of the by-product coking industry, with conservation of the former immense wastage of the gas and its valuable by-products during bee-hive operations.

Coke-Oven Gas

The crude oven gas entering the plant distributing system contains variable amounts of impurities, dependent on the type of coal carbonized and the temperatures and pressures maintained during the coking period.

Tar removal equipment follows the primary coolers, and while the static type is largely used, the removal of the tar content by recirculation of tar in the mechanical scrubber has been satisfactorily demonstrated. In this method, maintenance of the tar at a temperature above the dew-point of the gas assures a drier product, and permits operating temperatures exceeding that necessary for satisfactory operation of the static type, with the gas retaining more of its higher oils than in the latter case. This means of removal would eliminate some of the steps in the process of direct ammonia recovery, which are necessary in conjunction with static operation.

In some of the coking operations, the ammonia is recovered by water scrubbing with the production of a weak ammoniacal liquor which is worked up into both concentrated liquor and sulphate, depending on the comparative marketing conditions for these products. The strength of this solution will range from 5 to 15 grams per liter depending on the type of equipment engaged in its removal.

There is some removal of both CO_2 and H_2S due to interaction between them and the ammonia, the purifying effect naturally depending on the intimacy and time of contact as well as the strength of solution secured with different types. In one type, a double functioning of gas cooling and ammonia absorption is effected by dividing the operation into two stages. Recirculated, cooled, weak liquor in the first stages precipitates tar and naphthalene with a consequent improvement in the quality of the solution obtained in the absorption stage, and the elimination of the main difficulties in indirect cooling operations.

The saturator of the direct process is, in effect, a scrubber wherein the gas is subdivided into a number of jets by means of the slots in the cracker ring, the total slot area varying with the total volume of gas to be treated. Due to the elevated temperature in this process, the gas will pick up additional water vapor which involves final cooling to prevent emulsification of the oil used in the light oil scrubbers.

Removal of the light oil content and its preparation for use as motor fuel completes the usual series of by-products recovered in coking operations.

Mineral seal oil, of special characteristics as in the case of gasoline recovery, is employed for this purpose and the usual practice secures saturations of from 2.5 to 3.5 per cent, the variations usually following variations in oil and gas temperatures during absorption. Tower washers with grids for packing, operating in series of two or more units, are usually employed in this country for this recovery and during the past several decades there has been but slight modification of design.

In removing soluble vapors each of which possesses varying vapor tensions, such as ammonia or the various hydrocarbons, it is essential for both good recovery and high concentration that the solvent be maintained at as low a temperature as is economically possible. The latent heats of such vapors induce a considerable heating of the solvent, the extent of which will vary with their initial content in the gas, and with such increase in temperature the increased tension sets up an equilibrium between gas and solvent earlier than if cold. The installation of internal water-cooled coils in one type of mechanical scrubber has in the same operation effected a 33 per cent increase in the concentration above what would be secured if this provision were not made.

At one of the plants in this district the removal of hydrogen sulphid from the gas used for furnace heating, has been of advantage in improving the

*Reprint from Proceedings of Engineers' Society of Western Pennsylvania.

quality of the steel. This operation consists in scrubbing with a solution containing both carbonate and bicarbonate of soda, the H_2S forming principally a hydrosulphid with some fixed salts. Regeneration of this solution permits its recirculation, and with further development the sulphur is recovered in solid form.

Depending on both temperatures and pressures in the carbonizing chamber, from 0.7 to 1 pound of cyanogen per ton of coal may be produced, and its removal would also remove a considerable depreciation factor in plant equipment and the distributing system.

Ferrous sulphate, or copperas, in the presence of ammonia is an active extractive medium for this material, forming an insoluble ferrocyanide of iron and ammonium. This would afford a means of disposal of some of the pickling liquor and by utilizing the free acid content of this liquid reduce the amount of acid needed in the ammonium sulphate process. The ammonium sulphate produced in the reaction between the copperas and cyanogen would amount to approximately 50 per cent of the iron compound in weight.

Conversion of the insoluble ferrocyanide to other compounds, or its return to the ore pile for recovery of iron would still take care of two problems and show a credit to general operations.

Where the gas is to be transported for any distance, the removal of both excess water vapor and naphthalene by thorough scrubbing would aid in the distributing operation.

Producer Gas

Raw producer gas used in mill operations is generally used without any treatment for removal of the tars, ammonia, and carbon content.

Transportation of this gas involves the use of lined mains of large size to take care of the carbon deposits which result from successive condensation and redistillation or cracking of the tar. To keep the mains open, frequent burning-out of deposited carbon is necessary, with a consequent loss of the thermal value of this material.

Producer-gas tar, naturally of high carbon content, has readily responded to treatment when the temperature of the outlet water is 95 to 100 deg. F. as at this temperature it remains fluid and not "sticky" or plastic. This involves the use of reduced volumes of water in order not to chill the tar, and the mechanical scrubber has reduced the tar content of hot, raw gas by 97 per cent, in one operation. Removal of the tar close to the producer would prevent its degradation and the subsequent loss of carbon. A saving in the cost of the piping would likewise be effected.

Blast-Furnace Gas

The blast-furnace is essentially a huge gas producer with the constitution of the outgoing gases varying with the character of the raw materials charged, and with the thermal and chemical reactions occurring during the reduction of the ore.

The gaseous constituents and thermal value of the gas are directly affected by the coke rate per ton of product, and this factor as well as temperatures and pressures in the several reaction zones also influences the character and quantity of the solids carried in the gas. These solids consist of the finer particles of all materials in the burden together with "fume" and sublimes of the alkalis and metals, most of which in average practice in the northern United States are in the solid phase when leaving the furnace. In the reduction of ferro-manganese there is a larger quantity,

as well as a greater proportion of "fume" in the vapor phase due to the higher operating temperatures. These products have been aptly termed "metallurgical smoke." The first step in their removal is the condensation from the vapor to the solid state.

Compared with Lake ores there is from three to seven times as much potash in manganiferous ores, with southern ores carrying from two to six times the content of Lake ores. The "fume" problem is consequently increased in pig-iron production in the southern district and a greater depreciation factor in the life of refractory materials is a result.

While the insoluble dust recovered in wet scrubbing will show as much as 90 per cent passing through a 200-mesh screen, the particles of sublimes are even smaller. The emulsifying effect of this combination militates against the effective use of the gases of high calorific value in which they exist causing at times suspension of combustion under certain furnace conditions in both pig-iron and ferromanganese operations. The solids existing in blast-furnace gas as well as the vapor constituents recovered from the other gases are present in proportions representing but a few tenths of one per cent of the total weight of the gas. Satisfactory removal requires extreme penetration of the gas stream carrying either or both types of constituents, as it is impracticable from the operating standpoint to subdivide the gas into innumerable streams, and the gradual development of scrubbing equipment has been toward breaking up the liquid into as minute particles as possible in order to present the maximum amount of liquid surface with a consequent increase of penetration and intimacy of contact. The most effective removal of both vapors and solids is secured when the actual contact is at low gas velocity, since solid particles of light density can be wetted, weighted, and more easily precipitated in this case.

The greatest proportionate removal of insoluble dust particles is at the inlet zone where both gas and water are hottest, and where the steam flash due to the transition from superheated to saturated gas takes place thereby reducing the surface tension of these particles and effecting a more thorough wetting of them.

The alkaline fume products are water soluble and consist of both chlorid and sulphate combinations, with their solubility varying with both temperature and penetration.

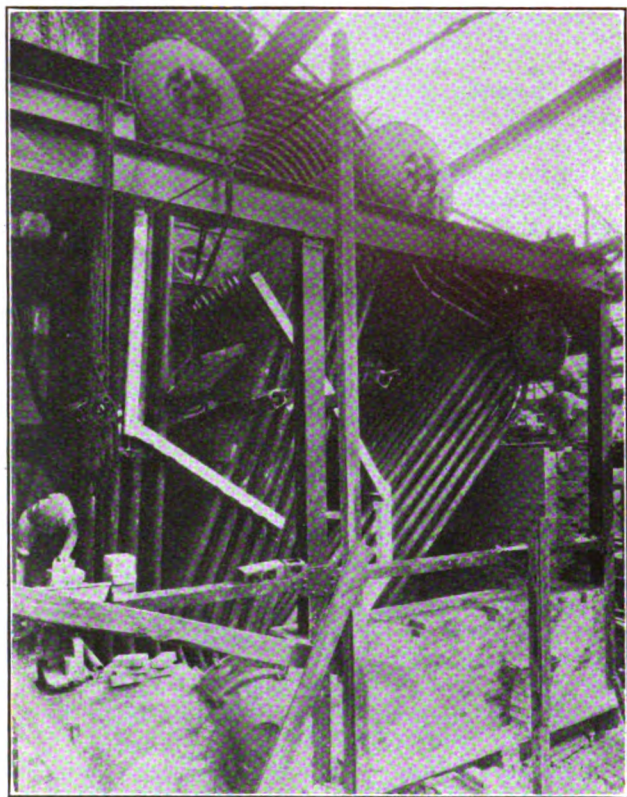
Recovery data developed in connection with the scrubbing of ferromanganese gas indicate an appreciable return from the by-product potash produced. The initial alkali content and the tonnage handled would be the determining factors in pig-iron operations.

In his investigations at Bethlehem several years ago, R. J. Wysor demonstrated that almost 70 per cent of the potash produced was in the furnace gas and therefore available for recovery in the scrubbing system. Such a product would have a high value as fertilizer material, so that it is possible by modern scrubbing treatment to eliminate with profit one of the serious handicaps to the effective use of furnace gas in the various types of combustion equipment.

Combustion is purely a chemical reaction consisting in the oxidation of either solid or gaseous carbon compounds with the evolution of heat. Like all such reactions, its intensity and rapidity are affected by the degree of dilution of either agent in the combination.

WITH THE EQUIPMENT MANUFACTURERS

A new method of baffling, patented by A. C. Danks, and for sale by The Engineering Company, 17 Battery Place, New York, is now on the market. In this construction, the baffles are arranged so that the gases of combustion cross the banks of tubes at right angles. This arrangement reduces the sharpness of the reversals or bends which the gases of combustion must make, in moving from one pass to the next, and improves the draft conditions. The arrangement also



results in an increase in area of the available heating surface in the first and second passes where the temperatures are higher, thus increasing the heat absorbing capacity of the apparatus and reducing stack temperatures. A further feature of construction, involving a departure from previous practice, and giving a higher efficiency, is the arrangement of the baffles so that the net cross sectional area in the passes from the first to the last gradually decreases, following in a measure, the law of contracting gases due to cooling. The velocity of the gases is thus prevented from being reduced, as would otherwise be the case, if the reduction in cross sectional area did not occur. This feature of construction, tends to prevent any reduction in the velocity of transit of the gases throughout the heating passageway of the boiler, and adds substantially to its efficiency. A further object is a larger net area or clearance space between the tubes at the various passes, such areas being in all cases greater than the damper areas so that the draft losses at the passes is reduced to a minimum.

The National Oil Gauge Company, Chicago, has recently placed upon the market the Oilmetre for indicating at a glance the actual level of oil or any other liquid in storage. The standard Oilmetre will indicate up to 5000 gallons, but it may be calibrated for any capacity without affecting its accuracy.

R. H. Beaumont Company, Philadelphia, has adopted Tru-Lay brand preformed wire rope, manufactured by the American Cable Company, New York, as standard equipment on all their various types of coal handling equipment. This change will not only increase the efficiency and lengthen the service of the equipment, but will eliminate hazards to workmen, since this rope will not "fly" or "explode" when cut or broken due to the fact that each wire and strand is preformed, then laid into a definite place, rather than being merely twisted into shape. In addition, it resists kinking and has practically no tendency to high strand—two features that permit of easier handling and more economical service.

A recent modification of the standard Universal Flanging Press, has been introduced by the Chambersburg Engineering Company. In addition to regular line of solid and sectional flanging which this machine will produce, upsetting, forging, and straightening operations also can be accommodated, due to the stops that have been added to the table.

The machine is equipped with two vertical pistons, the outer one being used for clamping the work, while the inner one is utilized for turning the flanging when the work is done sectionally. These pistons can be coupled to a single die for flanging in one operation. The horizontal ram is normally used for squaring and truing up the flanging around the die block upon which the plate is clamped.

With the stroke on the bed, the horizontal ram is also available for upsetting, straightening, and forging work. An interlocking device is provided for preventing the fouling of the vertical and horizontal rams. Arrangements are made to limit the strokes of all the rams to prevent damage to the machine.

Largest Steel Mill Turbine

The largest turbine generator ever used by a steel mill will be installed by the Illinois Steel Company at its Gary, Ind., plant. This equipment, which will be furnished by the General Electric Company, will produce 30,000 kw. at 25 cycles, 6600 volts, and will operate condensing.

The tendency of steel mills to use large prime movers is indicated, not only by this, but also by other similar installations to be made by other plants. The Tennessee Coal, Iron & Railroad Company is soon to install two 20,000-kw. turbine generators, and another unit of the same size will be installed by the Bethlehem Steel Company at Sparrows Point, Md.

TRADE NOTES

Armco Culvert Manufacturers' Association announces the opening of two new district offices. A district office is opened at Lincoln, Neb., with Mont C. Noble, formerly chief of the Bureau of Roads and Bridges, Nebraska State Department of Public Works, as district engineer in charge. This office will be in charge of association work in Nebraska, Kansas, Iowa and Missouri. A district office is opened also at East Point, Ga., with Tom M. Neibling, formerly research engineer of the Georgia State Highway Department, as district engineer in charge. This office will be in charge of association work in Alabama, Florida, Georgia, Louisiana, Mississippi, Tennessee, North Carolina, and South Carolina.

* * *

Pennsylvania Crusher Company, Philadelphia, announce John Alden Plimpton has been appointed western manager, in charge of the Chicago office, effective February 1, 1927. As western manager, Mr. Plimpton succeeds Mr. C. S. Darling.

* * *

The Blaw-Knox Company announces the addition to its engineering and selling forces of Mr. John C. White, president of the Arrowhead Iron Works of Pennsylvania, Inc. Mr. White has recently joined the organization of the Blaw-Knox Company and has been appointed sales manager of the steel grating and flooring department. He will be located at the general offices of the Blaw-Knox Company at Pittsburgh.

* * *

The Elliott Company, Jeannette, Pa., announces the following changes affecting the sales organization in the Pittsburgh district:

The Kerr turbine business in the Pittsburgh territory, formerly handled by R. M. Rush on an agency basis, has been transferred to the district office.

The Pittsburgh office of the former Ridgway Dynamo & Engine Company, recently taken over by the Elliott organization, has been consolidated with the district office, and J. F. Rodgers has been appointed assistant district manager.

The Pittsburgh district office is located at 718 Frick Bldg., telephone Atlantic 5000. All communications regarding Kerr or Ridgway equipment should be addressed to H. A. Pastre, district manager.

* * *

Capewell Horse Nail Company, Hartford, Conn., has re-elected the following officers: President, Dr. George C. F. Williams; vice president and general manager, L. L. Gaylord; vice president attorney, S. Williams; secretary, A. L. Shipman; treasurer, F. S. Rathbun; assistant secretary, C. T. Mitchell; superintendent, L. F. McLoughlin. The following directors were re-elected: Dr. Williams, Truman S. Lewis, Mr. Shipman, Francis T. Maxwell, Charles P. Cooley, S. Williams and Charles S. Thayer.

* * *

International Combustion Engineering Corporation, New York, has moved with its subsidiaries to its new home in the International Combustion Bldg., Madison Avenue, Thirty-fifth and Thirty-sixth Streets. The subsidiaries are Combustion Engineering Corporation, Ladd Water Tube Boiler Company, and

Raymond Brothers Impact Pulverizer Company, Ltd. The new building has 500,000 sq. ft., with provision for more when necessity arises. This contrasts with 7,000 sq. ft. occupied at its organization in 1920.

* * *

Johnson Steel & Wire Company, Worcester, Mass., has completed installation of equipment in its new plant and production of high carbon wire is nearing its full capacity of 200,000 lbs. per month. Charles D. Johnson is president and general manager, George Peace vice president, B. A. Johnson treasurer, and George G. Johnson assistant treasurer. Charles Johnson formerly was connected with the Worcester Wire Company, leaving that connection to form the new company.

TRADE PUBLICATIONS

The Jones & Laughlin Steel Corporation has recently distributed a leaflet describing a new product termed "Jalcase." This steel is especially adapted for case hardening and for forging where machinability is most important. It is recommended for gears, forgings and products of a like nature. Photomicrographs which are reproduced in the leaflet show the structure of the steel. A handbook setting forth in detail the characteristics of Jalcase will be mailed to those requesting a copy.

* * *

The Lincoln Electric Company of Cleveland has just issued the 1927 edition of the "Instruction Manual." This publication, which is revised annually to cover the latest practices used in manual electric arc welding, is of interest to practically everyone who uses arc welding. Among the subjects treated are: High speed steel welding, high pressure pipe welding, automobile frames, boiler repairs, welding cast iron, manganese steel welding, carbon arc welding, manufacture of machinery and equipment using welded steel in place of castings.

* * *

The Combustion Engineering Corporation has issued Catalog No. 19, describing small pulverizers manufactured by the Raymond Brothers Impact Pulverizer Company. This catalog goes into detail in explaining various pulverizing problems, and illustrates those pulverizers best adapted to various kinds of materials. It also includes a description of a complete air separating plant.

* * *

The Western Wheel Scraper Company is this year celebrating its fiftieth anniversary. To commemorate this event, the company has issued a most attractive catalog in which are fully illustrated and described the products manufactured. A brochure section, which is inserted in the fore part of the catalog, contains a history of the company from its establishment in 1877. Photographs show the construction and manner of operating the various types of dump cars as well as the service to which each type is especially fitted. Descriptive matter includes the capacities and dimensions. Equipment for road construction, plows, cars, scrapers, etc., are other products displayed in a way that will appeal to those interested in such equipment.

THE STEEL PLANT BRICK MASON

A Section Devoted to Items of General Interest to Blast Furnace and Steel Plant Brick Masons

The American Refractories Institute's spring meeting will be held this year on Wednesday and Thursday, May 18 and 19, at the Hotel Traymore, Atlantic City, N. J. The first day will be taken up by a business and technical session and on the second day there will be a golf tournament.

On February 11, at Frostburg, Md., the Savage Mountain Fire Brick Company was sold in its entirety to the United States Refractories Corporation of Mount Union, Pa. In the sale were included the plant together with all equipment, and the rich deposits of fire clay on Savage Mountain.

The officers of the United States Refractories Corporation are Thomas N. Kurtz, of Pittsburgh, president; C. V. Hackman of Mount Union, Pa., vice president; Victor L. Wallett of Mount Union, Pa., secretary-treasurer. These officers, together with Gurney A. Shuckhart of Frostburg, and P. N. Risser of Bedford, will comprise the board of directors of the Frostburg plant. This corporation, with headquarters at Mount Union, Pa., controls other brick plants at Mount Union and in Clearfield County, Pa.

The Savage Mountain Fire Brick Company was organized at Frostburg in the spring of 1864 and since that time has been engaged in the manufacture of high grade fire brick.

It was founded by the late L. M. Gorsuch and has been controlled by his heirs until the present.

The Pittsburgh sales office of the Savage Mountain Fire Brick Company will be transferred from the Federal Reserve Bldg. to 641 Oliver Bldg. Ralph E. MacDonald, sales manager of the company, will continue in charge of sales and will also handle the products of the U. S. Refractories Corporation along with Vance M. Norton, from the Oliver Bldg. office.

In a leaflet recently distributed by the La-

clede-Christy Clay Products Company, attention is directed to the fact that this company has been in business since 1844. The company was founded by James Green, who took an active interest in the manufacture of refractories, until his death in 1914. James Green was the father of John L. Green, now president of the company. The high alumina clays now mined by the company were thought to be useless until a research laboratory was established and methods devised for manufacturing products from these clays.

The Refractory Question Box

The Blast Furnace and Steel Plant Brick Mason will be glad to answer questions of a practical nature on the use of refractory materials in general steel mill practice. Questions pertaining to any particular brand of refractory will not be answered.

The Brick Mason, Blast Furnace and Steel Plant, Pittsburgh, Pa.

Dear sir: Not being associated with a steel plant, making their own steel, I have often wondered for what purposes magnesite is used. Could you tell me?

D. L. M.

Answer—Magnesite being a basic refractory material, it is used in basic open hearth steel furnaces for bottoms, side wall construction and ports. It is also used in mechanical puddling furnaces such as those operated by the Lebanon Iron Works and the Highland Iron and Steel Company and in the copper industry in their reverberatory furnaces.

Approval of a plan for the formation of an American Ceramic Research Council was one of the principal actions taken by the American Ceramic Society, which conducted its twenty-ninth annual meeting at the Book-Cadillac Hotel, Detroit, Mich., during the week beginning February 14.



Mr. J. C. Garbett, whose photograph appears above, was snapped with a most appropriate background. He is in his element when close to the "brick pile" as he has served 40 years either laying bricks, or instructing others how to lay them. Mr. Garbett began his work in 1887 at the Edgar Thomson Steel Works, with which company he was employed until 1897 when he left to accept a position with the National Tube Company at McKeesport. At the present time Mr. Garbett is in charge of all masonry construction at this latter plant. Forty years of service in his chosen work entitles him to recognition.

Metal-Kase Magnesite Brick in Open Hearth

By B. M. Larsen

In a review of open hearth developments which appeared in the January issue of "The Blast Furnace and Steel Plant," the writer discussed briefly the use of "metal-kase" shapes in side walls and bulkheads. As written, the discussion undoubtedly gives a wrong impression by indicating that metal-kase shapes could not be used successfully in side walls of the melting chamber. As a matter of fact, such shapes have been used with marked success in back walls in a number of shops.

It is difficult to rate exactly the service value of any refractory, due to varying service conditions in different plants. In this case, it may be most useful to describe a few actual service results in several shops. Metal-kase shapes are usually made by tamping a mix of burned magnesite in steel tubes, 13½ in. or 18 in. long; lengths of used boiler tubes are often used for this purpose. Such a body is intended to combine the high fusion point and resistance to slag action possessed by magnesite brick, with a much greater spalling resistance, spalling being the main cause of deterioration in a vertical wall of ordinary magnesite brick.

When these shapes are used in a wall which is exposed only at short intervals or not at all to temperatures above the melting point of the steel cases (about 2730 deg. F.) such service conditions are approximated in bulkhead or port end walls in an open hearth. Several plants are using metal-kase cylinders to form the upper portion of the end walls of gas ports, especially in the area opposite the port opening, where the outgoing gases impinge on the brick and cause a severe slag action from oxide particles suspended in the gas stream. Metal-kase walls in this area have given very much better service than silica brick. Temperatures in this zone of an open hearth are usually below or slightly above the melting point of the steel cases; these slowly oxidize and sinter or flux with the magnesite at their inner ends and the magnesite cores are supported over practically their whole length and thus prevented from spalling and cracking away.

While in a number of plants very satisfactory service is obtained from back walls built of "metal-kase" brick, their use in other parts of the furnace will be found to give even greater satisfaction.

By-Product Coke Oven Refractories

Although both clay and silica brick are used in the construction of coke ovens, the latter are much greater in importance and attention will only be given to these.

The manufacture of silica brick has been described repeatedly and there is little to add to this part of the subject. We would like to point out, however, that the development of this product is distinctly an American achievement and in this line, if in no other, our refractories industry is far in advance of foreign countries. Men interested in the manufacture of silica brick in England and Germany, who have recently visited our plants, have been amazed at the quality of our ware, the intricacy and size of shapes that are manufactured and the magnitude of the operations. These developments may have been forced through

demands of open hearth and coke oven operators for materials to withstand the stress of high temperatures, but credit is deserved, nevertheless.

The properties of silica brick that make them desirable for by-product coke ovens are extreme rigidity at high temperatures, good refractoriness, lack of shrinkage, good thermal conductivity, and high resistance to abrasion. It is fortunate, indeed, that these properties are obtainable in a product containing very cheap and abundant raw material. The objectionable properties of silica brick are the comparatively large amount of expansion and severe spalling tendencies. These are evident in all silica products, although spalling is not apt to take place above a red heat and does not cause much concern during the regular operation of coke ovens. Soft burned brick having a high proportion of quartz present and a poorly developed bond do not spall as readily as those that are hard burned, but these are subject to a large permanent expansion when used at high temperature and this would, of course, be very detrimental in a long battery of coke ovens.

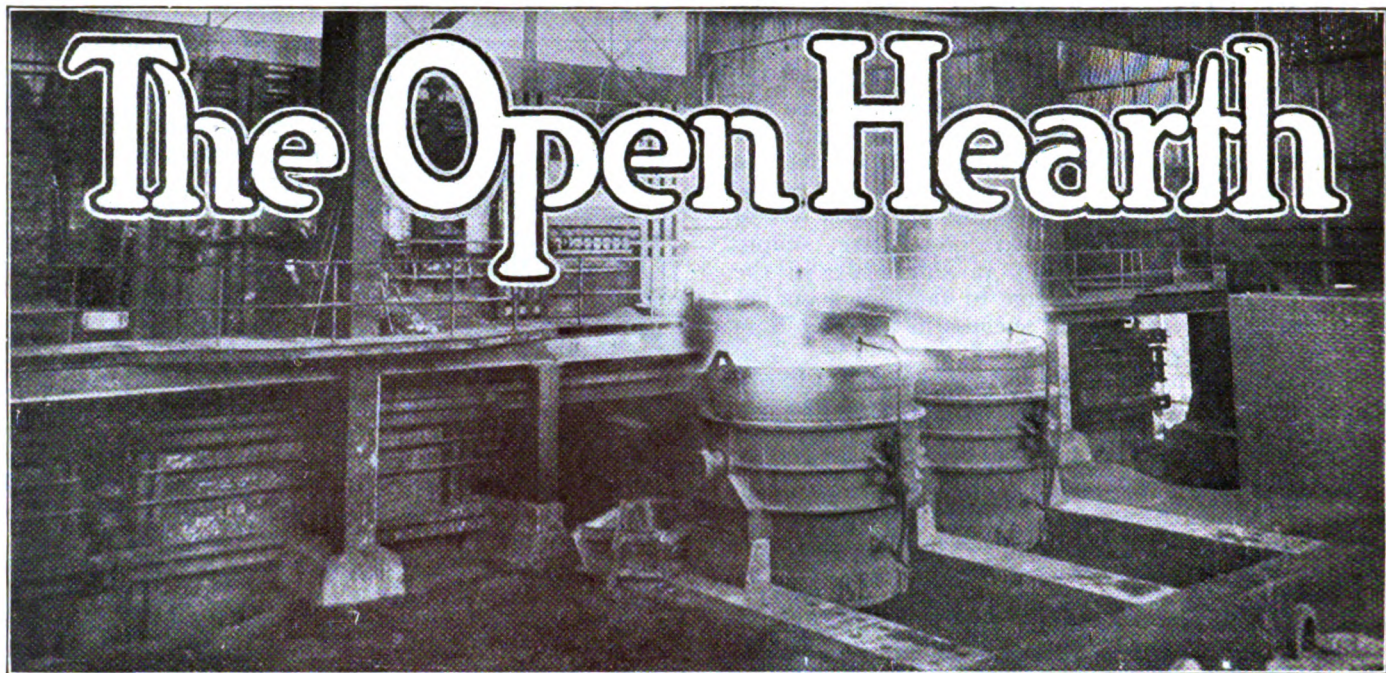
The resistance to abrasion of silica brick has been studied by Harvey and McGee. These investigators have found that resistance varies indirectly as the porosity where the product of only one manufacturer is considered, but with silica brick in general "the ability to resist abrasion does not appear to be dependent upon any one characteristic property of the brick, but may be influenced by any one or more of the following properties: Porosity, degree of burn, grind, quality of ganister, per cent lime, and "workmanship."

The high rigidity and refractoriness of silica brick are due in part at least to the absence of impurities in the rock selected for their manufacture. These properties are affected in an undesirable way by the usual fluxes and especially by the presence of an appreciable amount of alumina. This is recognized by manufacturers and probably accounts for the preference of some talus rock from which at least part of the clay that is occasionally found in seams in the quartzite deposits has been washed out. The practice of using 2 per cent of lime for a bond in silica brick has become so general as to be almost universal. When a much greater amount is used the refractoriness is noticeably affected and a strong product is not obtained with much less.

The comparatively high thermal conductivity that is attributed to silica brick is a property of the material itself although probably assisted materially by the relatively large and abundant pores present in these products. This is not as important, however, as would be the case if the material did not remain rigid at high temperatures and allow the use of thin walls, through which heat is transferred readily from the burning gases to the charge.

According to the most reliable authorities, fire brick was first made in New Jersey in 1812.

As a further index of the waste burden which the people of this country are supporting, half the coke industry still operates on the beehive process rather than using the modern by-product recovery process. On this basis alone the coke industry in undergoing losses of at least 50 per cent.



D. L. Mathias, editor of "Forging-Stamping-Heat Treating" since November, 1922, and also editor of "The Blast Furnace and Steel Plant" for the past year, resigned February 12th



to accept a position with Mackintosh-Hemphill Company, Pittsburgh, as Metallurgical Engineer. Mr. Mathias has had considerable experience in this work, as he served in a similar capacity with Mackintosh-Hemphill Company from 1914, after graduation from the Carnegie Institute of Technology, until 1920. He was also associated with the Brown Instrument Company, Philadelphia, as a pyrometer engineer. In addition to his duties as metallurgical engineer, he will also have charge of publicity and advertising, for which his past experience in publishing will qualify him. Mr. Mathias, who is a member of the American Society for Steel Treating, and the American Society for Testing Materials, will continue his connection with "The Blast Furnace and Steel Plant" and "Forging-Stamping-Heat Treating" as a member of the Editorial Advisory Board.

* * *

Seyern P. Ker, president of the Sharon Steel Hoop Company, Sharon, Pa., was the speaker at the annual dinner of the Iron and Steel Club of Detroit, held recently at the Detroit Athletic Club. His subject was "The Growth of the Steel Industry." The club is made up of the district managers of steel companies maintaining offices in Detroit. The following officers and directors have been elected for 1927: Earl Park, Superior Steel Corporation, president; T. H. Booth, Columbia Steel & Shafting Company, vice president; Harold Davey, Mansfield Sheet & Tin Plate Company, secretary-treasurer, and W. J. Hanna, Trumbull Steel Company; A. A. Keally, Sharon Steel Hoop Com-

pany; H. B. MacGregor, Newton Steel Company, and E. D. Pumphrey, Donner Steel Company, directors.

* * *

L. H. Burnett, recently elected vice president of the Carnegie Steel Company, started with that company 25 years ago. After graduating from Columbia University he entered the steel industry as a clerk to the solicitor of the Carnegie Steel Company. He successively held the positions of assistant solicitor, vice president of the land companies of the Carnegie Company, and then assistant to the president. Mr. Burnett is credited with being the sponsor of the active movement which the Carnegie Company has taken in promoting safety. He was born in Springfield, Ohio, September 14, 1874.

* * *

R. H. Bourne, formerly vice president and sales manager of the Whiting Corporation, Harvey, Ill., has been made senior vice president of the company and will devote a large part of his time to the sales management of the Grindle Fuel Equipment Company and the Joseph Harrington Company, subsidiaries of the Whiting organization. N. S. Lawrence, formerly vice president and assistant sales manager for the parent company, is now vice president and sales manager of that company and also of the Swenson Evaporator Company. He will be assisted by A. H. McDougall, vice president and consulting engineer, and E. H. Prussing, vice president in charge of district offices and agents.

* * *

E. S. Black has rejoined the American Manganese Steel Company, with his headquarters at Chicago Heights, Ill. His duties are those of Consulting Engineer, both mechanical and sales. Mr. A. H. Exton has also rejoined the Amsco organization, in the capacity of chief engineer.

* * *

George L. Anderson has been appointed district sales manager of the Indianapolis territory for the Union Drawn Steel Company, Beaver Falls, Pa. He will be assisted by M. A. Williams, with offices at 1310 Merchants Bank Bldg., Indianapolis.

Fred Hughes Moyer, recently elected vice president of the Mackintosh-Hemphill Company, Pittsburgh, was also made a director of the company at the annual meeting of stockholders on February 15. Other new directors named were Samuel McMillen, for many years the company's general superintendent; E. H. Haslam, at one time chief engineer and more recently vice president and general manager; W. C. Rice, formerly connected with the Pittsburgh Iron & Steel Foundry Company, Midland, Pa., now the Midland plant of the Mackintosh-Hemphill Company, and John W. Chalfant, Colonial Trust Company, Pittsburgh. J. R. Speer continues as president of the company, and Donald H. Baum as secretary treasurer. They, together with H. V. Baxter and Charles McKnight, were re-elected directors.

Frank I. Hoover, for many years with the Central Iron & Steel Company, Harrisburg, Pa., has been advanced to the position of assistant general manager of sales. He will be assistant to L. F. Nagle, general sales manager.

James Criswell has resigned as vice president of the Arrowhead Iron Works of Pennsylvania to become affiliated with the Blaw-Knox Company, Blawnox, Pa. He has been appointed sales manager of the steel grating department with headquarters at the company's general office at Pittsburgh.

Harry Howe has been appointed engineer of railway equipment for the Manganese Steel Forge Company, Philadelphia. Mr. Howe has been with the Pressed Steel Car Company as special engineer, having been connected with that company for 21 years.

E. T. Weir, president of Weirton Steel Company, left recently for a six weeks' stay in Bermuda.

Curtis B. Friday and Norman N. Hench have been appointed sales engineers in the rail bureau, general sales department, Illinois Steel Company, Chicago. Mr. Friday will specialize in wheels and forgings and Mr. Hench in track accessories.

OBITUARIES

Powell Stackhouse, one of the pioneers in the steel industry, died after a protracted illness at St. Petersburg, Fla., on February 4. Mr. Stackhouse began his business life at the age of fifteen as a clerk for his uncle, Daniel J. Morrell, who was then in charge of the store owned by the Cambria Iron Company, which company had been organized in 1852. After this apprenticeship, he acted as storekeeper until 1861, when he entered the Federal army, where he served until 1863. Mr. Stackhouse was then placed in charge of the real estate department of the steel company, from which position he was promoted to that of assistant general manager. In 1891, on the death of Edward Y. Townsend, then president of the Cambria Iron Company, Mr. Stackhouse was elected to the presidency, in which capacity he served until his successor, Mr. Charles S. Price, was appointed. He was a director and first vice president of the American Iron and Steel Institute.

Powell Stackhouse was reared under the rigorous discipline which was in vogue in the early days of the iron industry, in consequence of which he was accustomed to hard work and close attention to details. He always led a most active life.

Benjamin Nikolas Broido, chief engineer of the industrial department of The Superheater Company, of New York and Chicago, died suddenly at his home in New York, February 10, 1927. Mr. Broido was known throughout this country and abroad as a designer of exceptional ability. He was born in Wilna, Russia, in January, 1879, but his education was obtained in Germany, where he graduated in 1904 from Frederick's Polytechnic, Gothen. Mr. Broido came to this country in 1914 and took a post-graduate course in the City College of New York and Columbia University.

Gram Curtis, formerly chief engineer of the New Castle Works of the Carnegie Steel Company, died at his home in Drexel Hill, Pa., January 31. Mr. Curtis was identified with the development of the Bessemer process of making steel during its earlier days in the United States. Born May 2, 1844, in New York City, he was graduated from Cornell University, Ithaca, N. Y., in 1872. In 1897 the Shenango Valley Steel Company of New Castle began a program of expansion and Mr. Curtis accepted a position as chief engineer. Later this company was absorbed by the United States Steel Corporation, and became the New Castle Works of the Corporation's subsidiary, the Carnegie Steel Company. Mr. Curtis retired from active engineering in 1925 and moved to Drexel Hill, Pa., a suburb of Philadelphia.

James Howard Park, for many years identified with the steel business in Pittsburgh, died February 13 at Augusta, Ga. Mr. Park was born in Allegheny in 1853 and 20 years later began his career as a steel manufacturer with the firm of Park Brothers & Company. This firm was then operating the Black Diamond Steel Works which, in later years, was one of the plants absorbed in the formation of the Crucible Steel Company of America. Mr. Park was vice president and director of this latter company until his retirement from active business about 12 years ago. In his late years he devoted much time to philanthropic and civic interests and gave active support to many charitable institutions.

Justus H. Schwacke, until recently president of William Sellers & Co., Inc., Philadelphia, died February 17 at Boca Grande, Fla., aged 79 years. He became associated with the Sellers organization in 1862 and was elected secretary when the company was incorporated in 1886. He was made a director in 1902 and three years later became manager of the company. He served as president from 1922 until May 31, 1926, having retired to private life on the later date. Mr. Schwacke was active in the formation of the National Metal Trades Association and served as president in 1910 and 1911. He was also a member of the National Founders Association, and was for several years president of the Metal Manufacturers Association of Philadelphia. He was an honorary member of the latter organization and also an honorary member of the administrative council of the National Metal Trades Association.

NEWS OF THE PLANTS

The Koppers Construction Company has been awarded a contract for the design and erection of a by-product coke and gas plant for the Brooklyn Union Gas Company at Brooklyn, N. Y. This plant will consist of 74 Becker type combination coke and gas ovens and nine Koppers gas producers, with a complete coal and coke handling system, and complete equipment for the recovery of by-products. The plant will have a capacity of 1,750 tons of coal per day and a gas output of 20,000,000 cu. ft. per day.

* * *

W. A. Thomas, independent sheet maker, has announced that the proposed merger of six sheet producers in the Middle West has been definitely called off through failure to agree upon valuation terms and other details. An effort will be made to amalgamate several companies now operating in the Mahoning Valley.

* * *

Gillette Safety Razor Company, Boston, has developed two new products and has others in preparation, according to its engineering department. One is a surgeon's blade in all desired shapes, fitting a handle so the blade may be discarded when no longer usable. The other is a textile edge for use on power looms in the manufacture of carpets and rugs. This edge is said to last from four to six times as long as the present equipment, and has the further advantage of being easily removable. The Gillette company is now producing 2,400,000 razor blades and 125,000 razors a day.

* * *

Mahoning Valley Steel Company, Youngstown, Ohio, has re-elected officers and directors, who are: President, W. Aubrey Thomas; vice president and treasurer, John Hosack; secretary, John M. Thomas; assistant secretary, Robert W. Wilson; assistant secretary, George Wick. Directors are W. Aubrey Thomas, John M. Thomas, J. D. Waddell, M. T. Klingan and John Hosack.

* * *

Binney Castings Company has been established at 1805 Clinton Street, Toledo, Ohio. The organization is headed by R. L. Binney, who for eight years was chief metallurgist of the Bunting Brass & Bronze Company of that city. The new foundry has been engaged for some time in experimental work and expects to enter production on various non-ferrous alloys, including a special bronze for glass molds and a long life gear metal.

* * *

Pottstown Metal Products Company, Inc., Pottstown, Pa., manufacturer of riveted and welded tanks, stacks and heavy plate work, is building a plant for production of plate work of every kind. The plant is expected to be in operation by April. P. L. Keiser is president of the company. He formerly was president of the Steel Plate Products Company, Pottstown, Pa., selling his holdings in October and forming the new company.

* * *

Purchase of the entire holding of the late T. M. Adams in the Norton Iron Works Company and the

Ashland Steel Company, Ashland, Ky., has been consummated by the American Rolling Mill Company, according to an announcement made by J. C. Miller, general manager Ashland, Ky., works, American Rolling Mill Company. Negotiations had been in progress for several weeks and were concluded earlier than anticipated by the interested parties. Plans for the operation of the two companies have not been made public beyond the fact that the blast furnace of the Norton company will be blown in when necessary repairs have been completed. At a meeting of the Norton Iron Works Company the following officers were chosen: J. H. Frantz, president; J. C. Miller, vice president; R. C. Phillips, secretary; C. W. Verity, treasurer; G. W. McNeilly, assistant secretary and assistant treasurer. Directors are C. W. Verity, J. H. Frantz, C. R. Hook, R. C. Phillips, J. C. Miller, S. R. Rectanus and W. W. Sebald. The Norton Iron Works Company owned, in addition to a blast furnace of 350 tons daily capacity, a wire mill, nail mill, wire cloth factory and a foundry. The Ashland Steel Company operated a blooming mill and a rod mill.

* * *

No. 1 strip mill at the plant of the Trumbull Steel Company, Warren, O., is being rearranged and improved for rolling wider strip by the installation of 4-high mills, new shears, hot reel, and bar piling and weighing equipment. A cooling bed, 45 ft. wide and 250 ft. long with shears, bar piling and weighing equipment is being installed in the No. 2 hot strip mill.

* * *

A notable core oven installation is that at Flint, Mich., for the new Buick foundry. There will be nine overhead horizontal units, eight 145 ft. long and one 117 ft. long. Each oven will be 15 ft. 6 in. wide and 9 ft. 9 in. high inside.

The green cores will be loaded directly upon a continuous trolley conveyor, carrying racks of five shelves each 38 x 48 in. There will be 83 racks to each oven unit, and the conveyor will have a variable speed drive to govern the baking period. All oven units will be heated by oil. In the design, economy of floor space and high operating efficiency were the objective.

COMING MEETINGS

March 23-25—The Engineering Extension Department of Purdue University announces its second Annual Conference on Industrial Electric Heating at Lafayette, Ind., under the direction of the School of Electrical Engineering with the electric utilities and the manufacturers of electric heating equipment co-operating.

* * *

April 4-6—The American Society of Mechanical Engineers Mid-West regional meeting at Kansas City.

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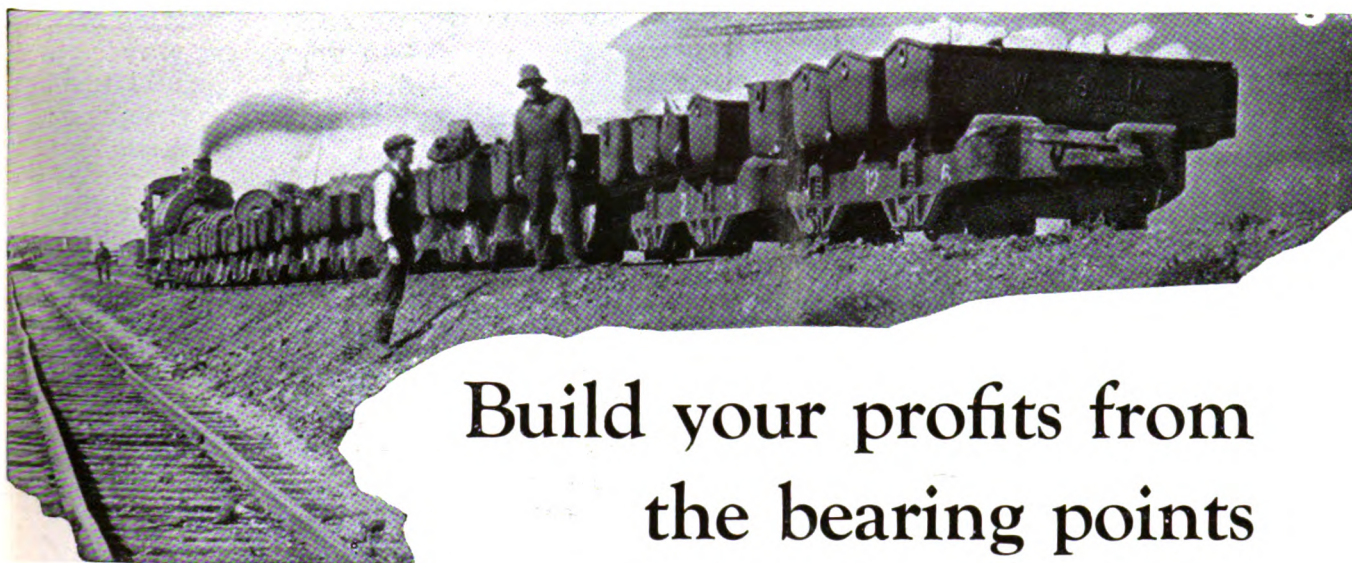
May 23-26—American Society of Mechanical Engineers meeting at White Sulphur Springs, W. Va.

The Blast Furnace *and* Steel Plant

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PITTSBURGH, PA., MARCH, 1927

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